Clinical Oral Investigations (2020) 24:1113–1124
https://doi.org/10.1007/s00784-020-03210-x

REVIEW

Titanium abutment surface modifications and peri-implant tissue behavior: a systematic review and meta-analysis

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Received: 6 August 2019 / Accepted: 9 January 2020 / Published online: 18 January 2020

Abstract

Objectives To evaluate the effect of various titanium abutment modifications on the behaviour of peri-implant soft tissue healing, inflammation and maintenance.

Material and methods An electronic database research until 30 April 2019 was performed. A meta-analysis (MA) for each outcome parameter was performed by using the random-effects models with the DerSimonian-Laird estimator.

Results Ten studies were included in the present review. Four studies with a long follow-up (5–6 years) reported the outcomes in a heterogeneous way and were suitable for MA. Six studies (4 RCT, 2 CCT) including 118 patients and 182 implants dealing with a modified healing abutment surface and short follow-up were selected for MA. The MA for PI and BoP as outcome showed no significant differences between surfaces (PI: $P = 0.091$; BoP: $P = 0.099$). The MA for PD as outcome showed no significant differences between surfaces ($P = 0.488$). No statistical significance was found by evaluating each mixed-effects model for potential moderators (type of study, study design, number of implants, follow-up length). The other four studies with a longer follow-up (5–6 years) reported contradictory results depending on the surface treatment investigated.

Conclusions Within their limits, the present findings suggest that peri-implant soft tissue may not be affected by the surface treatment of titanium abutments on the short term. Contrasting results are reported in longer follow-up periods depending on the technique used to modify the abutment.

Clinical relevance Clinicians should carefully evaluate the use of a modified titanium surface in their practice. Even if no differences in terms of inflammation are present at short term, these findings need to be validated in long-term studies.

Keywords Healing abutment · Abutment · Surface · Roughness · Soft tissue · Titanium

Introduction

The use of osseointegrated titanium implants is nowadays a routine treatment modality in dentistry. The success of dental implants is affected by the surface properties of titanium implants as they influence molecular interactions, cellular response and thereby, bone remodelling. Machined titanium implants have been used clinically since more than 50 years [1].

Over the last years, surface titanium modifications have been evaluated and moderately roughened surfaces have shown the capability to promote a more rapid bone formation than machined surfaces [2, 3].

Surface roughness at the bone level plays an important role for cellular reactions, tissue healing and implant stability [4, 5]. Different methods such as machining, air-abrasion, acid etching, electrochemical oxidation and laser treatment are used to alter surface topographies on titanium implant surfaces at various thicknesses in order to promote osseointegration [1].

However, the role of modified titanium surfaces at the transmucosal level, in contact with peri-implant soft tissue, is still unclear. It has been suggested that peri-implant soft

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Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00784-020-03210-x) contains supplementary material, which is available to authorized users.

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tissue may create a biological seal protecting peri-implant bone from the highly contaminated oral environment [6] and reducing the risk of bone resorption [7].

Some studies have shown that using machined titanium abutments there is the presence of a circular system of collagen fibers around the abutment [8]. On the other hand, other studies have recently shown that a modified prosthetic abutment surface promotes the creation of a perpendicular collagen fiber attachment to the abutment [9, 10]. Cell adhesion to the abutment surface is mediated by the formation of hemidesmosomes, similarly to that found at natural teeth [11, 12]. It may thus be anticipated that the treatment of titanium surface treatment could influence the quality/quantity of cell attachment as well as the healing process and host response [11–13].

However, a rougher surface at the soft tissue level may provide a better potential matrix for bacteria to grow on [14] increasing the potential risk of a plaque-induced inflammatory reaction that may subsequently lead to peri-implant mucositis and/or peri-implantitis [15, 16].

However, at present, it is unclear to what effect the various titanium abutments may influence soft tissue response.

The aim of the present systematic review was therefore to evaluate the effect of various titanium abutment modifications on the behavior of peri-implant soft tissue healing, inflammation and maintenance. The hypothesis to be tested was that in systemically healthy patients with at least one titanium abutment connected to an implant, the modified titanium could favor soft peri-implant tissue healing and maintenance without increasing tissue inflammation.

Material and methods

The present review is reported in accordance with the guidelines of *Transparent Reporting of Systematic Reviews and Meta-analyses* (PRISMA statement: Liberati et al., 2009 [17]; Moher et al., 2009 [18]). The PRISMA checklist for this study is reported in the electronic supplementary material (ESM-Table 1). The review protocol was registered in the international prospective register of systematic reviews (PROSPERO) (CRD42019128877).

The proposed focused question for the present review was: "Which is the effect of titanium healing abutments with different surface modifications on soft peri-implant tissue behavior in healthy patients?"

The focused question was established according to the PICO strategy [19]:

- Population: Healthy patients with at least one titanium abutment connected to a dental implant.
- Intervention: Any abutment surface modification different from machined titanium
- Comparison: Any type of machined titanium abutment
- Outcomes: Peri-implant tissue indexes; i.e. plaque index (PI), bleeding on probing (BOP) and/or probing depth (PD).

Search strategy

A systematic literature search was performed for the period 1 January 1980 to 14 April 2019, and further updated until 30 April 2019, in the following databases: MEDLINE/PubMed, Scopus, Science Citation Index Expanded from Web of Science and Cochrane Library. Dental implant(s), dental implantation, abutment(s), healing/prosthetic/implant abutment, (randomized) clinical trial, titanium and humans were used as the main keywords, with AND/OR as Boolean operators. All reference lists of the selected studies were checked for cross-references. For more details regarding queries and their outputs for each database, see ESM-Table 2.

The studies were included if they met the following inclusion criteria:

- Randomized clinical trials (RCTs);
- Controlled clinical trials (CCT);
- Assessment of peri-implant soft tissue health periodontal indexes: PI and/or BOP and/or PD at the implant level;
- At least 10 implants inserted;
- Surface of the abutment clearly described;
- At least 1-month healing after abutment connection;

Studies not meeting all inclusion criteria were excluded. Also, reports based on questionnaires, interviews, hence studies without clinical examination of the patients, reviews, redundant publications and case reports were excluded.

The following studies were also excluded from the present review:

- studies comparing the effect of different implant-abutment connections, or different implant shapes;
- studies investigating mini-implants and/or orthodontic anchorage;

No restrictions in terms of publication language or year of publication were applied.

Study selection and data extraction

Two reviewers (PP and MM) did the primary search by screening independently the titles and abstracts. The same reviewers evaluated the full-text of the studies meeting the inclusion criteria, or those with insufficient data in the title and abstract to make a clear decision. Any disagreement was resolved by discussion with a third reviewer (GS). When multiple publications of the same research group/center described potentially overlapping case series, the more recent publication was used, if eligible. The inter-reviewer reliability was evaluated with percentages of agreement and kappa coefficients. Data were extracted independently by the two reviewers using a specifically designed excel spreadsheet. The extracted data included authors, journal, year of publication, country, study design, number of subjects included, number of implants included, drop-outs, characteristics of trial participants (including age, gender, smoking habit, parafunctions); follow-up period, implant cumulative survival rate, abutment roughness, treatment used to modify the titanium surface, eventual decontamination of the abutment surface, periodontal indices [PI, BOP, PD, gingival index (GI), mean bone loss], and technical or biological complications. Disagreement regarding data extraction was resolved by discussion.

For PI and BOP, the original percentage values were converted to a raw data considering the number of implants for experimental and control groups. For PD, the original values expressed in mm and reported as mean ± standard deviation (SD) were directly used.

If multiple time points data were present, the one with the longest follow-up was selected as long as the healing abutments were in place and therefore before the prosthesis delivery.

All the authors were contacted by email to provide additional data needed to perform the qualitative or quantitative analysis and all of them responded and provided data that were not present in their published papers.

Quality assessment—risk of BIAS in individual studies

A quality assessment of the selected studies was performed following the Cochrane Handbook for Systematic Reviews of Interventions [20]. The following quality criteria were assessed: sequence generation, allocation concealment, systematic differences in the care provided to members of the different study groups other than the intervention under investigation (performance bias), systematic differences between groups in how outcomes were determined (detection bias), unequal loss of participants from study groups (attrition bias), within-study selective outcome reporting (selective reporting bias) and other potential risk of bias. These criteria were rated as low, unclear or high risk of bias, depending on the descriptions given for each item in the selected studies.

Quality assessment—risk of BIAS across studies

The publication bias was evaluated using a funnel plot and the Egger's regression test for funnel plot asymmetry, with standard error as predictor [21]. In a funnel plot, the recommended choice for the y-axis is the standard error [22]. In the absence of publication bias and heterogeneity, it is expected to see the selected studies forming a funnel shape, with the majority of these falling inside the pseudo-confidence region. A contour-enhanced funnel plot was also provided [22], which is centered not at the model estimate (as is usually done with a conventional funnel plot), but at "0" (assumed as the value under the null hypothesis of no effect). Several levels of statistical significance of the points/studies are indicated by the shaded regions (unshaded region: $P > 0.10$; dark gray-shaded region: P value between 0.10 and 0.05; medium gray-shaded region: P values between 0.05 and 0.01; the region outside of the funnel: $P < 0.01$). A contour-enhanced funnel plot is useful for detecting publication bias due to the suppression of non-significant studies.

Statistical analysis

The statistical heterogeneity among studies was expressed as τ^2 and estimated by the Cochran's Q test. The I^2 was calculated to assess variability due to heterogeneity rather than chance ($I^2 \leq 25\%$: low; $I^2 > 25\%$ and $\leq 50\%$: moderate; $I^2 > 50\%$ and $\leq 75\%$: considerable; $I^2 > 75\%$: high heterogeneity). H^2 was calculated as the ratio between total and sampling variability. The estimates of the effects were expressed as log risk ratio (RR) and 95% confidence interval (95% CI) (test ± and control ± implants for PI and BOP) or standardized mean difference (SMD). To reduce the correlation between the log RR and the corresponding sampling variances, a "smoothed" estimate of the sampling variances was adopted. For studies with zero values, a 0.5 value was added to obtain continuity corrections. Study-specific estimates were pooled with both the fixed and random-effects models, with the DerSimonian-Laird (DL) estimator. In the fixed random-effects models, the observed effects or outcomes of the selected studies are assumed to be unbiased and normally distributed. Conversely, in the random-effects models, the selected studies and their outcomes are assumed to be a random selection from a larger population of studies. The random-effects models were evaluated for each effect size without and with moderator variables; in this last case, the corresponding mixed-effects models were obtained, where the coefficients from the fitted models estimate the relationship between the average true effect/outcome in the population of studies and the moderator variables included in the same models. For models including moderators, an omnibus test of all the model coefficients was conducted, where the test statistics of the individual coefficients are based on a Chi-square distribution with n degrees of freedom (where n is the number of evaluated coefficients). The Knapp and Hartung method was used to adjust the standard errors of the estimated coefficients, which helps to account for the uncertainty in the estimate of residual

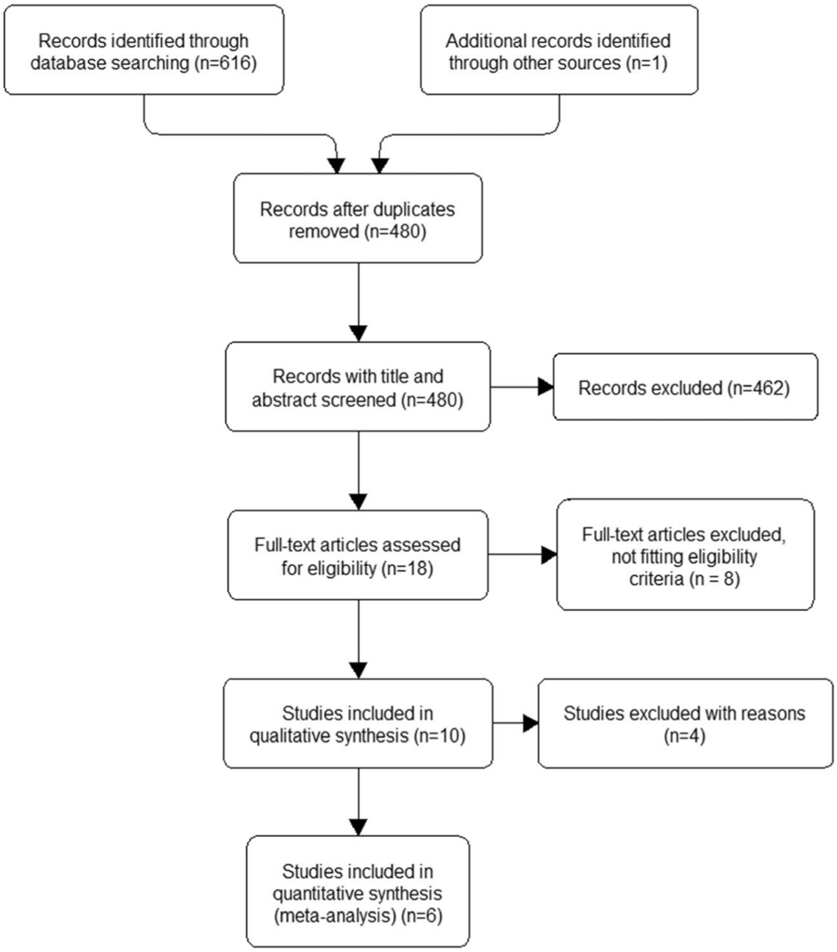

Fig. 1 PRISMA flow diagram of the study selection process

heterogeneity. Without moderators in the models, the same Cochran's Q test reported above was used to evaluate whether the variability in the observed effect sizes was larger than would be expected based on sampling variability alone. When moderators were included in the model, the Q_E test was used to evaluate residual heterogeneity.

Forest plot was created for each measured outcome to illustrate the effects in the meta-analysis of the different studies and the global estimation. For further evaluation of heterogeneity, also radial and normal quantile-quantile (Q-Q) plots were showed. A radial plot may be considered as a scatter plot of standardized estimates against reciprocals of standard errors. On the right-hand side of the plot, an arc is drawn corresponding to the observed effect sizes/outcomes, while a line projected from (0, 0) through a particular point within the plot onto this arc indicates the value of the observed effect size/outcome for that point. A normal Q-Q plot is able to show the distribution of the residual heterogeneity, subgroups in the data and/or publication bias. Statistical significance was assumed in each test with P value < 0.05. Statistical analysis was carried out by using the R software (version 3.6.0; R Foundation for Statistical Computing. Vienna, Austria) with the metafor package (version 2.1-0) [23].

Results

Search

The flow diagram reporting screening and selection of studies according to PRISMA is presented in Fig. 1. After duplicate removal ($n = 136$), 480 records were evaluated for titles and abstracts (agreement = 94.23%; kappa = 0.68; 95% CI [0.33–0.76]; $P < 0.001$). Of these records, 462 were excluded and 18 evaluated for full-text analysis (agreement = 97.89%; kappa = 0.97; 95% CI [0.90–1.00]; $P < 0.001$)). Reasons for exclusions are reported in ESM-Table 3. Then, 10 articles were included for qualitative analysis [24–33]. Six articles dealing about healing abutment surface modification with short follow-up and outcomes expressed in the same unit of measure were included in the meta-analysis. Four other articles dealing with abutment surface modification in "in-function implant" with a similar medium follow-up period of 5–6 years and inhomogeneities in data reporting and clinical scenario were not included in the meta-analysis but a qualitative analysis was done [30–33].

Table 1 Risk of bias assessment according to the Cochrane Collaboration recommendations

	Author	Selection bias sequence generation	Selection bias allocation concealment	Performance bias	Detection bias	Attrition bias	Selective reporting bias	Other potential risk of bias
1	Hall et al. 2019	Low	Low	Low	Low	Low	Low	Low
2	Garcia et al. 2018	Low	Low	Low	Low	Low	Unclear	Low
3	Schwarz et al. 2018	Low	Low	Low	Low	Low	Low	Low
4	Menini et al. 2017	Low	Low	High	High	Low	Unclear	Low
5	Degidi et al. 2012	Low	Low	High	High	Low	Unclear	Low
6	Baldi et al. 2009	Unclear	Low	High	High	Low	Unclear	Low
7	Canullo et al. 2016	Low	Low	Low	Low	Low	High	Low
8	Canullo et al. 2017	Low	Low	Low	Low	Low	High	Low
9	Gothberg et al. 2017	Low	Low	Low	Low	Low	Unclear	Low
10	Raes et al. 2018	Low	Low	Low	HIgh	Low	Low	Low

Quality assessment—risk of BIAS in individual studies

Table 1 depicts the scores for each criterion of the included studies. Performance and detection bias were considered high in Menini et al. [27], Baldi et al. [29], and Degidi et al. [28], due to the different appearance of test and control abutments that prevented blinding of the clinician. Detection bias was considered at high risk in Raes et al. [30] because the abutments were partially visible and the clinical parameters could not be recorded blinded. Selective reporting bias was high in Canullo et al. [32, 33] because some outcomes were not reported in the studies.

Characteristics of the included studies in the meta-analysis—healing abutment

Applying the criteria described above, a total of 6 studies including 118 patients and 182 implants were selected. The mean follow-up period was 12.67 ± 6.53 weeks (median: 11 weeks) [24–29] and the periodontal parameters were recorded when healing abutments were still in place. The mean PI index was 44.84%, BOP 9.23% and PD 2.01 mm in the modified abutments, and 27.8%, 9.77% and 1.90 mm in the machined ones, respectively. No loss of implants occurred. A brief description of each selected study is reported in Tables 2, 3 and 4. Only the studies by Menini et al. [27] and Degidi et al. [28] reported all three outcomes assumed in this systematic review. The studies of Garcia et al. [25] and Baldi et al. [29] reported PI and BOP as outcome, while the study of Hall et al. [24] reported only PI as outcome. Schwarz et al. [26] reported only BOP and PD.

Meta-analysis assuming PI as outcome

The random-effects model did not show significant heterogeneity ($\tau^2 = 0$, $I^2 = 0\%$, Q = 3.5777; $P = 0.4662$), with $H^2 =$ 1.00 (95%CI from 1.00 to 7.71). The pooled log RR was 0.41 (95% CI: − 0.07–0.88), with no significant differences between studies ($P = 0.091$). The forest plot of the random-effects model with DL estimator is reported in Fig. 2, while the plots for evaluating heterogeneity are presented in ESM-Fig. 1. The Egger's regression test for funnel plot asymmetry did not find statistical significance ($P = 0.511$).

Table 2 Main characteristics of the studies included in the meta-analysis

	Author	Country	Study type	Study design	No. of patients	No. of implants	Intervention (healing abutment surface)	Timing for periodontal parameter evaluation (weeks)
1	Hall et al. 2019	Sweden	RCT	Split mouth	32	64 (32 test 32 ctr)	Nanostrucured anodized titanium	6
2	Garcia et al. 2018	Spain	RCT	Parallel	30	30 (15 test 15 ctr)	Plasma of argon	10
3	Schwarz et al. 2018	Germany	RCT	Parallel	28	28 (15 test 13 ctr)	Laser-treated collar	12
4	Menini et al. 2017	Italy	RCT	Split mouth	10	20 (10 test 10 ctr)	Acid etched	8
5	Degidi et al. 2012	Italy	RCT	Split mouth	10	20 (10 test 10 ctr)	Acid etched	24
6	Baldi et al. 2009	Italy	RCT	Split mouth	8	20 (10 test 10 ctr)	Acid etched	16

Table 3 Main outcomes of the studies included in the meta-analysis

	Author	PI test Pos	PI Test Neg	PI Cont Pos	PI Cont Neg	BOP test Pos	BOP test Neg	BOP Cont Pos	BOP Cont Neg	PD test mean (SD)	PD Cont mean (SD)
1	Hall et al. 2019	0.16	0.84	0.19	0.81						
2	Garcia et al. 2018	0.16	0.84	0.19	0.81	0.09	0.91	0.19	0.81		
3	Schwarz et al. 2018					0.08	0.92	0.10	0.90	1.79 (0.83)	1.76 (0.64)
4	Menini et al. 2017	0.55	0.45	0.36	0.64	0.02	0.98	0.00	1.00	2.09 (0.74)	1.92 (0.73)
5	Degidi et al. 2012	0.80	0.20	0.42	0.57	0.22	0.78	0.15	0.85	2.15 (0.37)	2.03 (0.4)
6	Baldi et al. 2009	0.57	0.42	0.22	0.78	0.05	0.95	0.05	0.95		

By entering in the random-effects model with DL estimator several moderators (mixed-effects models), no statistical significance was found for type of study (test for moderator: $P = 0.180$; Q_E test for residual heterogeneity: $P = 0.618$), study design ($P = 0.382$; Q_E test: $P = 0.446$), number of implants ($P = 0.244$; Q_E test: $P = 0.548$) or follow-up length ($P = 0.182$; Q_E test: $P = 0.615$). The result of the fixed-effects model for PI as outcome is identical to that obtained in the random effects model.

Meta-analysis assuming BOP as outcome

The random-effects model has showed no significant heterogeneity ($\tau^2 = 0$, $I^2 = 0\%$, Q = 1.872; $P = 0.759$), with $H^2 = 1.00$ (95%CI from 1.00 to 3.60). The pooled log RR was − 0.01 (95% CI: − 1.12–1.11), with no significant differences between studies ($P = 0.992$). Forest plot of the random-effects model with DL estimator is reported in Fig. 3, while the plots for evaluating heterogeneity are presented in ESM-Fig. 2. The Egger’s regression test for funnel plot asymmetry did not find statistical significance ($P = 0.448$).

By entering in the random-effects model with DL estimator several moderators (mixed-effects models), no statistical significance was found for type of study (test for moderator: $P = 0.437$; Q_E test for residual heterogeneity: $P = 0.781$), study design ($P = 0.100$; Q_E test: $P = 0.923$), number of implants ($P = 0.056$; QE test: $P = 0.953$) or follow-up length ($P = 0.485$; Q_E test: $P = 0.768$). The result of the fixed-effects model for BOP as outcome is identical to that obtained in the random effects model.

Meta-analysis of standardized mean differences for PD

The random-effects model has showed no significant heterogeneity ($\tau^2 = 0$, $I^2 = 0\%$, $Q = 0.214$; $P = 0.898$), with $H^2 = 1.00$ (95%CI from 1.00 to 3.97). No changes in the model occurred when restricted maximum-likelihood or empirical Bayes were used as further estimators (data not shown). The pooled SMD was 0.17 (95% CI: − 0.31–0.65), with no significant differences between studies ($P = 0.488$). The forest plot of the random-effects model with DL estimator is reported in Fig. 4, while the plots for evaluating heterogeneity are presented in ESM-Fig. 3. The Egger’s regression test for funnel plot asymmetry did not find statistical significance ($P = 0.654$).

No significant results were obtained by entering the same moderators evaluated for PI and BOP (data not shown). In any case, the low number of studies enrolled for PD makes this analysis of low reliability. The result of the fixed-effects model is identical to that obtained in the random effects model.

Characteristics of the studies included in the systematic review (“in function” implants)

A total of 4 studies including 107 patients and 212 implants were included in the qualitative synthesis. A meta-analysis was not possible for the great heterogeneity of the studies and/or of the data [30–33]. Main characteristics are reported in Table 4.

The longest follow-up times of the four included studies vary from 5 [30–32] to 6 years [33].

Raes et al. [30] analyzed both fully edentulous patients and perio-patients with teeth in the antagonist jaw having remaining pockets rehabilitated with full-arch fixed prostheses or overdentures. Titanium abutments were machined or oxidized (TiUnite). Results over a 5-year period showed increased bone loss, BoP and PD next to TiUnite abutments. No information was provided on the hygiene protocol and the cumulative survival rate at the 5-year follow-up was 97.6% for machined and 100% for oxidized implants/abutments. Authors concluded that in patients with a history of severe periodontitis, minimally rough implants showed more favorable clinical parameters after 5 years of loading, when compared with moderately rough implants.

Göthberg et al. [31] in a study on partially edentulous patients rehabilitated with both delayed or immediate loading procedure analyzed the behavior of soft tissue next to

Table 4 Main characteristics and outcomes of studies included

Author	Year	Country	N. pz	N. imp	Notes	Test	Prosthesis type	Periodontal measurements	BOP/PI
Raes et al.	2018	Belgium	15	84 (42 test 42 ctr)	Perio patients, some patients present resiudual teeth with pockets. 1 implant failed in the control group	Oxidized abutment (TiUnite)	Full arch fixed or overdenture	6 sites for implant	yes/no
Canullo et al. (healthy)	2017	Spain	18	18 (9 test 9 ctr)	Single tooth premolar area	Plasma of Argon	Single implant	6 sites for implant	yes/no
Canullo et al. (perio)	2016	Spain	30	30 (15 test 15 ctr)	Esthetic area (premolar to premolar)	Plasma of Argon	Single Implant	6 sites for implant	yes/no
Gothberg et al.	2017	Sweden	44	80 (40 test 40 ctr)	Test group is immediate loading, control is delayed loading. In one test group the prosthesis is directly connected at implant level.	Oxidized abutment (TiUnite)	Partial prosthesis	PI 4 sites for implant PPD and BOP 6 sites for implant	Modified Mombelli index
Hall et al.	2019	Sweden	35	70 (35test 35 ctr)		Nanostrucured anodized titanium	Healing abutments	NA	Modified Mombelli index
Garcia et al.	2018	Spain	30	30 (15 test 15 ctr)		Plasma of Argon	Healing abutments	4 sites for implant	yes/no
Schwarz et al.	2018	Germany	28	28 (15 test 13 ctr)		Laser-microgrooved	Healing abutments	6 sites for implant	Modified Mombelli index
Menini et al.	2017	Italy	10	20 (10 test 10 ctr)		Acid etched	Healing abutments	4 sites for implant	yes/no
Degidi et al.	2012	Brazil	10	20 (10 test 10 ctr)		Acid etched	Healing abutments	4 sites for implant	yes/no
Baldi et al.	2009	Italy	8	20 (10 test 10 ctr)		Acid etched	Healing abutments	4 sites for implant	yes/no

Author	Follow-up	PI test	PI control	BoP test	BoP control	PD test mean (SD)	PD control mean (SD)	BL test mean (SD)	BL control mean (SD)
Raes et al.	5 years			3.78 ± 2.28	2.76 ± 2.52	4.19 ± 2.61	3.09 ± 1.01	1.65 ± 1.65	1 ± 0.9
Canullo et al. (healthy)	6 years	19 ± 3.8%	20 ± 4.5%	14 ± 3%	16 ± 3%	3.4 ± 0.35	3.2 ± 0.69	0.93 ± 0.69	0.22 ± 0.30
Canullo et al. (perio)	5 years	13.3%	13.3%	6.60%	20%	2.9 ± 0.45	2.8 ± 0.91	0.21–0.21	0.65–0.36
Gothberg et al.	5 years	requested	requested	requested	requested	requested	requested	2.01 (0.22)[a]	1.61 (0.25)[a]
Hall et al.	6 weeks	15.60%	18.70%						
Garcia et al.	2 weeks	16.10%	19.30%	8.60%	19%				
Schwarz et al.	12 weeks		–	7.80%	9.83%	1.79 (0.83)	1.76 (0.64)		
Menini et al.	3 months	55%	36%	2.27%	0%	2.09 (0.74)	1.92 (0.73)		
Degidi et al.	6 months	80%	42.50%	22.50%	15%	2.15 (0.37)	2.03 (0.4)		
Baldi et al.	3 months	57.50%	22.50%	5%	5%				

[a] Standard error

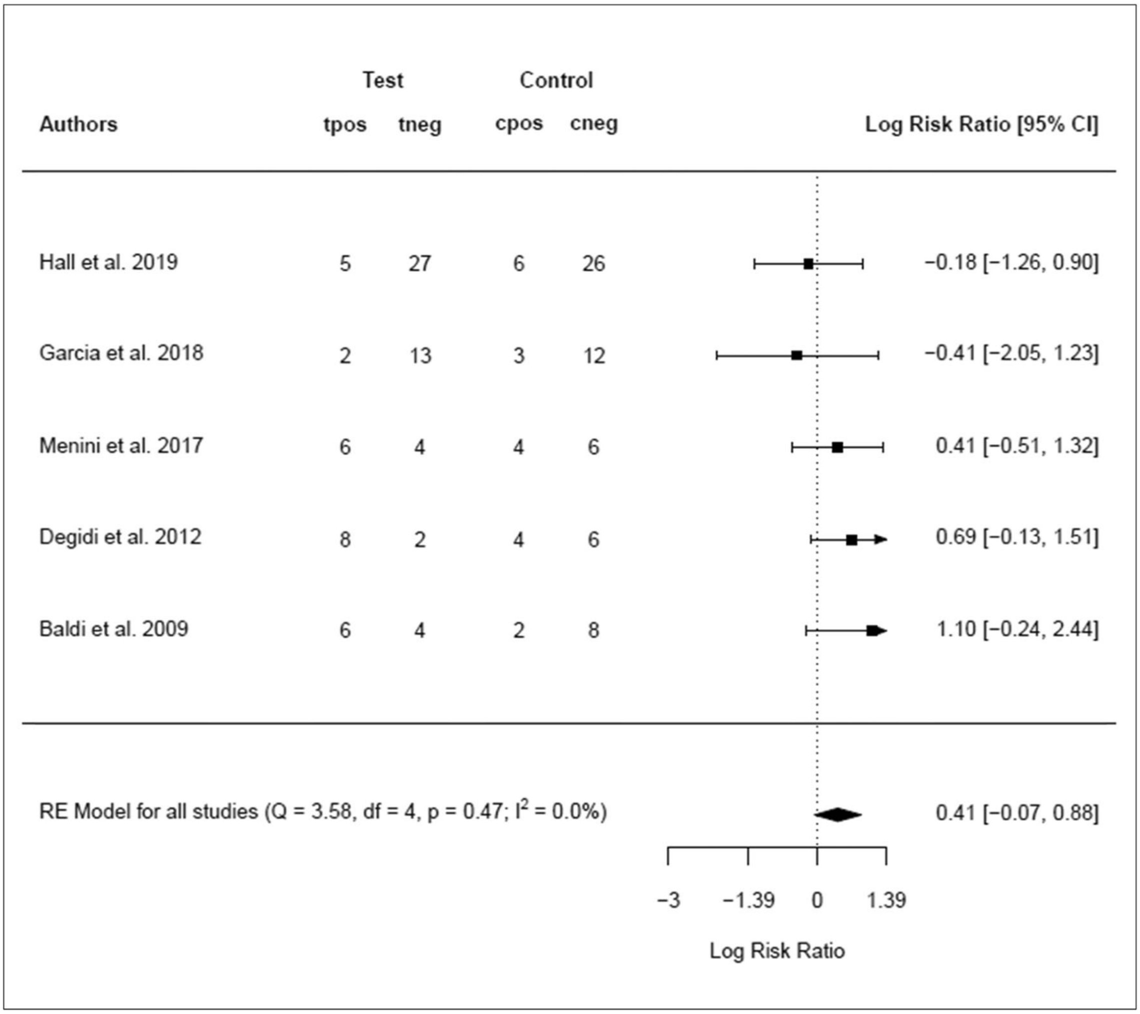

Fig. 2 Forest plot for the random-effects model with DerSimonian-Laird estimator, assuming the plaque index as outcome

machined and TiUnite abutments or the soft tissue near the structure directly in contact with the implants. No raw periodontal parameters were available except for bone level, but, on the base of their observations, the authors refuted the hypothesis that a moderately rough (oxidized) abutment promotes a soft tissue seal and protection of bone from the surrounding oral environment. Additionally, less bone resorption was identified around TiUnite implants/abutments (bone level: 2.01 vs 1.61 mm next to machined implants). According to the study design, only patients with a good level of oral hygiene were included in the study. Additionally at each recall visit, the examiner judged if the patient required professional cleaning and/or re-instruction.

Conversely, Canullo et al. [32, 33] in two different studies analyzed the effect of a plasma of argon surface treatment on titanium abutments on single implants in the esthetic zone both in healthy and in previously periodontal patients. The two studies reported a reduced BoP, a similar PD and a reduced bone loss in the plasma of argon-treated groups compared to titanium machined without plasma of argon activation at 5 and 6 years of follow-up. Patients were recalled for supportive periodontal therapy between 3 nor 6 months. Neither implant nor prosthetic failures and complications were detected in the analyzed patients of both studies.

The only quantitative parameter included in all of the four studies was bone loss, although in Göthberg et al. [31], the standard error and not the standard deviation was reported. Mean bone loss in the four papers was 1.2 mm in the modified and 0.87 mm in the titanium-machined abutments at the 5-/6-year follow-up.

Discussion

The present meta-analysis analyzing peri-implant tissue behavior around titanium abutment surface modifications did not reveal any variation in terms of PI, BOP and PD between machined and modified titanium healing abutments in the short term.

These findings are in agreement with the results of a recent systematic review analyzing the impact of the abutment material, macroscopic design, surface topography and surface manipulation [6]. According to Sanz-Martin et al. [6], surface topography fails to have a significant influence on peri-implant soft tissue. In fact, only the abutment material (zirconium vs. titanium) may have an effect on the inflammatory status [6].

On the contrary, outcomes of abutments on “in function” implants reported contradictory results in the medium term (5–6 years) depending on the type of surface treatment. In fact, based on two of the included studies, plasma of argon seemed able to improve the behavior of peri-implant soft tissue in the medium period and also showed reduced bone loss [32, 33].

Conversely, studies evaluating oxidized abutments reported a more favorable outcome for abutment with a machined titanium surface [30, 31].

The findings of the present systematic review seem to contradict the traditional hypothesis that an increased surface roughness would facilitate biofilm formation and therefore could have a negative influence on clinical periodontal parameters [14, 34]. Indeed, the present results appear to support the thesis that soft tissue attachment may be improved by moderately rough surfaces. In fact, at the early stage, a rough surfaced abutment could be beneficial for soft tissue integration. However, in a longer follow-up, this beneficial effect seems to get lost without detrimental effects, although, in some studies, a higher biofilm formation on modified surfaces was noticed.

One of the limitations of the present review is that different surface modification treatments were included; Menini et al., Baldi et al. and Degidi et al. [27–29] evaluated healing abutments with an acid etched surface. Hall. et al. [24] analyzed an anodized titanium oxide surface containing anatase, which has been reported to have antimicrobial properties able to reduce bacterial adherence to abutments. Göthberg et al. [31] and Raes et al. [30] used an oxidized surface (TiUnite); Schwarz et al. [26] used a modified abutment where 0.7 mm of the abutment collar presented a laser microgrooved surface. Garcia et al. [25] and Canullo et al. [32, 33] on the contrary analyzed a machined titanium surface modified with the use of plasma of argon treatment. In contrast with the other surface treatments investigated, it must be noted that plasma treatment does not change titanium micro-topography, but can activate the surfaces at the atomic and molecular levels, increasing surface wettability, preserving the integrity of the titanium surface [32]. This activation was demonstrated to enhance the activity of cells at the tissue–implant interface [32]. However, the effect of plasma of argon treatment on the early stages of healing after implant insertion still needs to be demonstrated.

An additional limitation may be represented by the number of re/disconnection of the abutments. In the studies with a

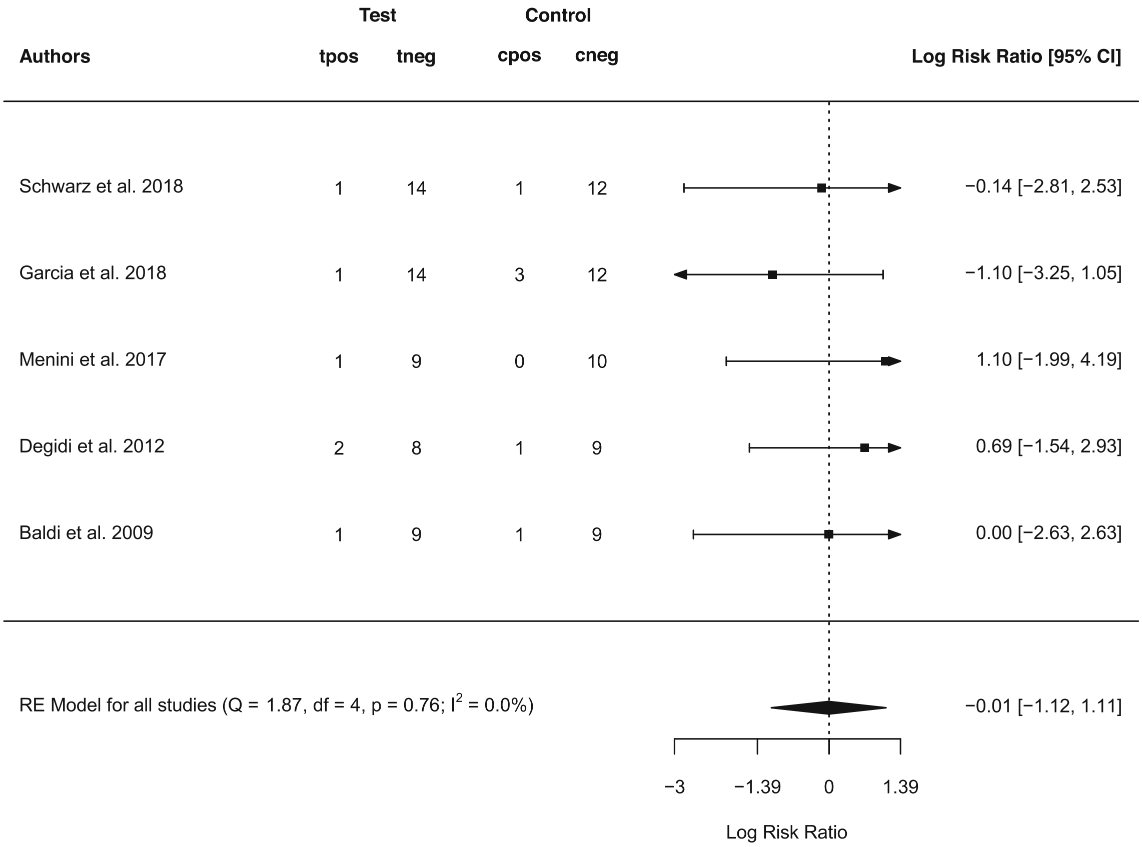

Fig. 3 Forest plot for the random-effects model with DerSimonian-Laird estimator, assuming the bleeding on probing as outcome

short follow-up period, healing abutments were used and they were never disconnected during the study period in the longer follow-up studies, only the two analyzing plasma of argon effect [32, 33] adopted a one-abutment/one-time prosthetic workflow. This approach is the only one that allows a stable soft tissue adaptation to the abutment. In all other cases, the adopted prosthetic workflow might have induced a soft tissue/abutment detachment which probably reduced the possible positive effect of a rough surfaced abutment.

In the present systematic review, strict criteria for study selection have been adopted, with the aim of reducing heterogeneity. In fact, in a recent meta-analysis on the effects of modified abutment characteristics on peri-implant soft tissue health [6], a high heterogeneity was reported (up to $I^2 > 90\%$ when materials different from titanium were evaluated). This high heterogeneity was due to several factors, such as the number of materials compared, the widely different follow-up period (from 6 to 86.4 months), and the multiplicity of outcomes reported in the enrolled studies. Such a high level of heterogeneity prevents the possibility of drawing robust conclusions that might be useful for clinicians.

Nevertheless, a constitutive heterogeneity regarding the outcomes evaluated in each selected study was found and several studies have been excluded because they did not record/report the outcomes of interest of the present review. Although six studies were included in the meta-analysis, only five or three studies fitted the meta-analytic models applied for each outcome (PI, BOP and PD). Moreover, these outcomes were originally expressed in different ways (percentages or mean ± SD), not allowing aggregation into a single forest plot.

In addition, an extensive pattern of plots was adopted to detect the risk of bias across studies (conventional and contour-enhanced funnel plots, radial plot, normal Q-Q plots), wider than usually reported in most meta-analyses. The selected studies fell within the pseudo-confidence region of the funnel plots for each outcome, with no significance at the Egger's regression test for funnel plot asymmetry, suggesting absence of publication bias. Conversely, no single study resulted at low risk of bias for all the Cochrane quality assessment criteria. More generally, the assessment of publication bias depends on the number of published papers, and a minimum number of 10 studies is desirable for conventional meta-analyses. On the other hand, in a previous survey to assess the application of statistical tests for funnel plot asymmetry in the meta-analyses of the Cochrane Database of Systematic Reviews, in the three-quarters or more of the 6873 included meta-analyses fewer than 10 studies were examined (3526 meta-analyses enrolled 3 or 4 studies, while 2479 meta-analyses enrolled from 5 to 9 studies) [35].

As an additional limitation, the follow-up of the studies included in the meta-analysis was short. In fact, these studies evaluated healing abutments that after bone healing were

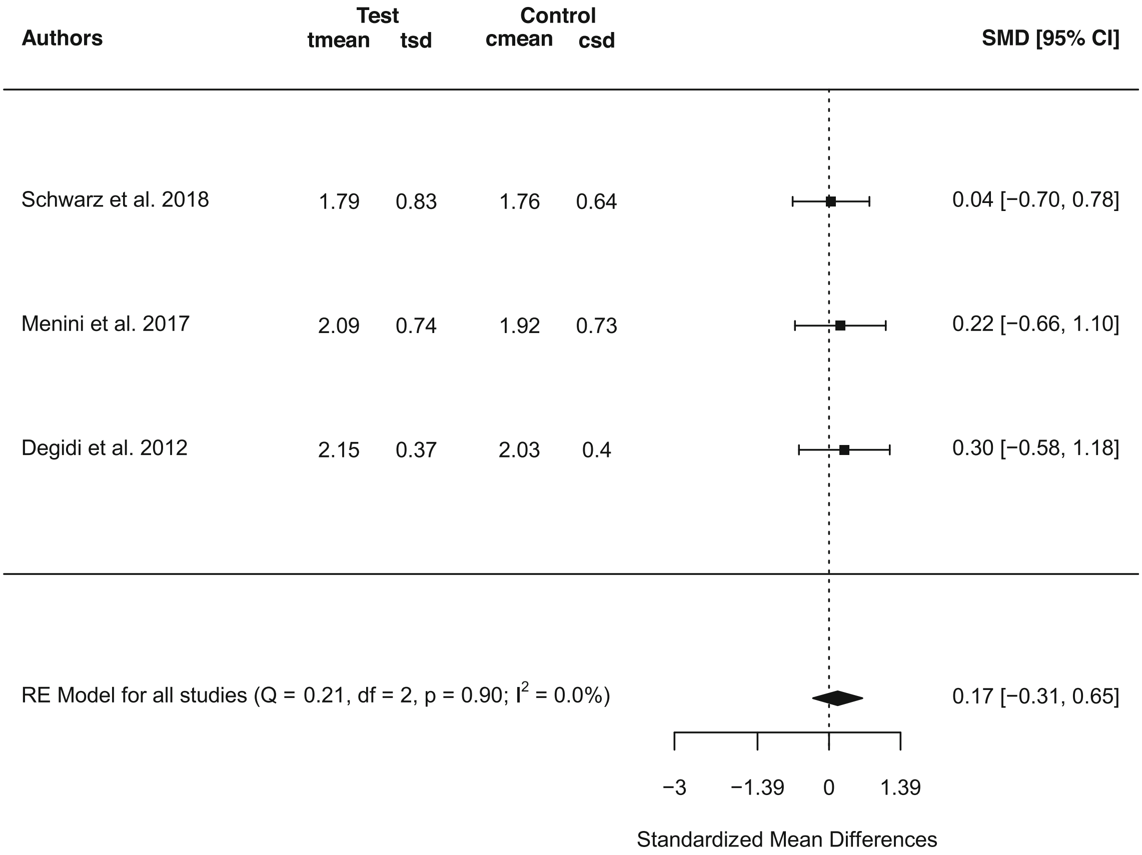

Fig. 4 Forest plot of the random-effects model with DerSimonian-Laird estimator, assuming probing depth as outcome

removed in order to take impressions and proceed with the realization of the final prosthetic rehabilitation. This fact must be taken into consideration and the lack of differences found in the analysis may be insufficient to draw robust conclusions. Also, the four articles with longer follow-up and evaluating abutments screwed on "in function" implants presented contrasting results depending on the technique used to modify the abutment, thus preventing a shared outcome. As a consequence, further research is needed and in particular histological analyses would be useful to confirm the hypothesis that modified surfaces enhance soft tissue sealing around titanium implants.

When interpreting the evaluated literature, it needs to be pointed to the great heterogeneity among periodontal indices used in the various studies. Since most studies have evaluated PI, BOP and PD, these parameters were selected as outcomes for the present meta-analysis. Therefore, it is recommended that future studies should systematically evaluate and report these indices in order to allow reliable comparisons between studies.

Conclusion

Within their limits, the present findings suggest that peri-implant soft tissue does not seem to be negatively affected by the surface treatments of titanium abutments on the short term. On the other hand, contrasting results are reported in longer follow-up depending on the prosthetic workflow and the technique used to modify the abutment.

Funding information This study was self-supported.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors. All procedures performed in the included studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent For this type of study, formal consent is not required.

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