Published online in advance by J-STAGE

J Prosthodont Res. 2023; **(**): ****–****

OPEN ACCESS JPR Prosthodontic Research

Journal of Prosthodontic Research

Review article

Effects of abutment materials on peri-implant soft tissue health and stability: A network meta-analysis

Paolo Pesce [a,#], Massimo Del Fabbro [b,c,#], Maria Menini [a], Emanuele De Giovanni [a], Marco Annunziata [d,e], Shahnawaz Khijmatgar [b], Luigi Canullo [f,*]

[a] Department of Surgical Sciences (DISC), Division of Prosthodontics and Implant Prosthodontics, University of Genoa, L. Rosanna Benzi, Genoa, Italy, [b] Department of Biomedical, Surgical, and Dental Sciences, University of Milan, Milan, Italy, [c] Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy, [d] Multidisciplinary Department of Medical-Surgical and Dental Specialties, University of Campania Luigi Vanvitelli, Naples, Italy, [e] Private Practice, Rome, Italy, [f] Department of Periodontology, University of Bern, Switzerland

Abstract

Purpose: This systematic review aimed to evaluate the effect of the abutment material on peri-implant soft tissue health and stability.
Study Selection: An electronic and hand search was conducted until February 2022. Only prospective randomized trials (RCTs) and controlled clinical trials (CCTs) comparing titanium abutments with abutments made of different materials, with a follow-up of at least 6 months, were selected by two independent reviewers. Data on marginal bone loss (MBL) and peri-implant tissue indexes, i.e., plaque index (PI), bleeding on probing (BOP), probing depth (PD), and recession (REC), were collected. The risk of bias for RCTs and non-RCTs was evaluated according to the tool reported in the Cochrane Handbook for Systematic Reviews of Interventions and the ROBINS-I tool, respectively. Both pairwise and network meta-analyses (NMA) were performed.
Results: We included 18 relevant studies from 1,437 identified studies. Overall, 612 patients were treated, and 848 abutments were inserted. Five studies presented a low risk of bias. Pairwise meta-analysis showed that, as compared to titanium, zirconia abutments presented a significantly reduced MBL (0.20 mm, 95% Confidence Interval CI [0.14–0.26], $P < 0.00001$). No significant differences were found for the other outcomes. In the NMA, zirconia abutments demonstrated an 83.3% probability of achieving the highest rank in PI, an 87.0% in BOP, and a 65.0% in PD outcome, suggesting that zirconia abutments generally performed better than titanium and alumina abutments.
Conclusions: Within the limits of the present study, zirconia abutments seem a viable alternative to titanium ones.

Keywords: Systematic review, Dental implants, Abutment, Peri-implant tissue

Received 29 August 2022, Accepted 15 February 2023, Available online 18 April 2023

1. Introduction

Replacing severely compromised or missing teeth with dental implants to restore function and aesthetics represents a successful therapy with a high long-term success rate[1]. However, different technical, mechanical, or biological complications may occur, compromising the implant's success[2]. Some of these failures can be observed in a short duration; however, most take place after years of function[3]. Among them, peri-implant infection is considered one of the most important causes of failure[4,5]. The establishment and maintenance of healthy peri-implant soft tissue are considered key factors for the long-term success of dental implants[6].

The intimate contact between the peri-implant mucosa and dental implant abutment makes the soft tissue seal around dental implants. This seal is crucial to protect soft and hard tissue from bacterial contamination and prevent the development of peri-implant disease, which may lead to bone loss and affect dental implant survival or success[7].

The adhesion, colonization, and proliferation of bacteria on dental implant abutments largely depend on surface properties, like surface free energy, roughness, and compatibility[8–13].

Strategies to reduce microbial adhesion and biofilm formation on implant abutment surfaces and the consequent risk of peri-implant disease have been introduced. These include the use of titanium abutments with a modified surface, cleaning methods of the abutments before their use, and the use of different abutment materials[14–20].

Historically, titanium abutments have been the gold standard and are still widely used. Titanium abutments are biocompatible and have optimal mechanical resistance[21], a very high survival rate, and few mechanical complications[22].

DOI: https://doi.org/10.2186/jpr.JPR_D_22_00223

#These authors equally contributed to the manuscript and share the first authorship
***Corresponding author:** Luigi Canullo, Department of Periodontology, University of Bern, Switzerland.
E-mail address: luigicanullo@yahoo.com

One of the major drawbacks of titanium abutments is their dark grayish color, which could hamper the aesthetic outcome, especially in patients with a thin gingival phenotype and in aesthetic areas[23].

For these reasons, other materials have been proposed to create dental abutments. These include alumina, gold-hued titanium, and zirconia. Alumina abutments are characterized by good biocompatibility and aesthetics; however, some studies have reported a lower resistance with a risk of fracture during clinical use[24]. Gold alloys result in better aesthetic outcomes than titanium abutments; however, they are not comparable with ceramics and have higher costs[25].

Over the past few years, zirconia abutments have become more popular because they seem to combine high mechanical strength and biocompatibility with good aesthetic properties due to their white color[26,27]. Additionally, experimental *in vitro* and *in vivo* studies have shown similar biological features compared to titanium abutments in microbial adhesion and soft tissue integration[28–30].

In light of the considerable number of different implant abutments available nowadays, this systematic review aimed to examine the clinical outcomes of abutments made of different materials. Specifically, the aim was to evaluate the effect of the abutment material on peri-implant hard and soft tissue health and stability.

2. Methods

This review was reported following the PRISMA guidelines (http://www.prisma-statement.org/). The review protocol was registered with PROSPERO (submission CRD42021234431).

The proposed focused question was: What is the effect of the abutment material on soft tissue health and stability?

The focused questions were elaborated following the PICOT format[31] (Stone, 2002), where:

Population: Healthy patients with abutments connected to dental implants.

Intervention: Any abutment material other than titanium.

Comparison: Titanium abutments.

Outcomes: Main outcome: Marginal bone loss (MBL). Secondary outcomes: peri-implant tissue indexes, i.e., plaque index (PI), bleeding on probing (BOP) and/or probing depth (PD), and recession (REC).

Time: At least 6 months of follow-up after abutment connection.

2.1. Eligibility criteria

Randomized controlled trials (RCTs) and controlled clinical trials (CCTs) investigating abutments made with different materials were included. We considered parallel and split-mouth designs. Only studies in which titanium abutments were used in the control groups were considered. Only studies with data on bone loss and periodontal parameters that included a 6-month follow-up after abutment connection were considered. Case reports, animal studies, and *in vitro* studies were excluded.

2.2. Search strategy

A literature search was carried out using electronic databases (MEDLINE (PubMed), Cochrane Central Register of Controlled Trials, and Scopus). A PubMed search was created and adapted for each database: ("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]) AND ("abutment"[All Fields] OR "abutment s"[All Fields] OR "abutments"[All Fields]) AND ("titanium"[MeSH Terms] OR "titanium"[All Fields] OR "titaniums"[All Fields]) AND ("zirconia"[All Fields] OR "zirconias"[All Fields] OR "zirconium oxide"[Supplementary Concept] OR "zirconium oxide"[All Fields] OR "zirconia"[All Fields] OR "gold"[All Fields] OR "PEEK"[All Fields]).

The last electronic search was conducted in February 2022. A hand search was performed in the following journals: Journal of Prosthetic Dentistry, International Journal of Prosthodontics, Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, Clinical Oral Investigations, International (ex-European) Journal of Oral Implantology, Implant Dentistry, International Journal of Oral and Maxillofacial Implants, International Journal of Periodontics and Restorative Dentistry, The reference lists of all identified studies and relevant systematic reviews were checked for additional studies. No language restriction was placed. Furthermore, we searched for grey literature, including conference abstracts, proceedings, and theses, on the following databases: www.greylit.org and www.opengrey.eu.

2.3. Study selection

Two authors (PP and EDG) screened the titles and abstracts of the selected articles to identify all studies meeting the inclusion criteria. Cohen's Kappa statistics were used to assess the agreement between examiners. When the abstract was unavailable or insufficient to allow unequivocal evaluation, the full text was obtained. Disagreements were resolved by discussion or by consulting a third reviewer (MDF). The full text of all the eligible articles was downloaded. The reasons for full-text exclusion were noted.

2.4. Data collection

We used an Excel data sheet (Microsoft Corp.) to collect data. Two authors (PP and EDG) extracted the data. The variables extracted were study design, country, sponsor, abutment material, coverage employed, age, smoking status of included patients, mean bone loss, probing depth (PD), bleeding on probing, plaque index, recession, complications, and abutment survival.

2.5. Risk of bias in assessment

Two co-authors (KS and PP) independently assessed the articles for different rating domains of bias. The risk of bias for RCTs was assessed according to the Cochrane Handbook for Systematic Reviews of Interventions (Higgins 2017). Differences in opinion and disagreements were resolved by discussing with another co-author (MDF). The rating of bias was defined for each domain as high, low, or unclear. Each potential source of bias was classified as high (causes serious weakness of confidence in results), low (unlikely to seriously alter the results), or unclear (raises some doubt about the results). The risk of bias judgments across different trials for each of the domains listed was summarized and evaluated across these domains: random, sequence generation, allocation concealment, blinding of outcome assessment, incomplete outcome data, selective outcome reporting, and other biases. The risk of bias in non-RCTs was assessed by the ROBINS-I tool.

2.6. Data analysis

Because the outcomes investigated in this study could be influenced by various factors, including the position or site of the abutment, the surgical technique (e.g., flap or flapless), implant type, surface roughness, soft tissue phenotype, oral hygiene, prosthesis material and design, a random-effects model based on DerSimonian and Laird was considered appropriate to account for this variability. The analysis was performed using pairwise and network meta-analysis to obtain estimates for primary outcomes. The extent of the effect was expressed as a mean difference (MD) along with 95% confidence intervals (CIs). We planned to estimate the heterogeneity using Cochran's test, considering a significance threshold of $P < 0.01$ and using I^2 statistics (describes the total percentage of variation across studies due to heterogeneity rather than chance). Significant heterogeneity was considered when the value of I^2 was >50%. The software RevMan (Review Manager Version 5.4, 2020; The Nordic Cochrane Center; The Cochrane Collaboration) was used for pairwise meta-analysis computations. In case of differences between follow-ups, materials used, and outcome measures, we planned to explore these with subgroup analysis (provided there is sufficient data, recognizing the difficulty of assessing heterogeneity with a small number of studies)[32,33]. The generic inverse variance method was applied using RevMan by combining RCTs and CCTs. A meta-analysis was performed when at least three studies with similar comparisons reporting the same outcome measures were found.

The results of the main outcome from RCTs and CCTs were compared by subgroup analysis to investigate if the study design had an effect.

When feasible, missing standard deviations were estimated using the methods described in section 7.7.3 of the Cochrane Handbook for Systematic Reviews of Interventions, Version 5.1.0 (Higgins 2011).

2.7. Network meta-analysis

Direct and indirect evidences from RCTs and CCTs were combined to determine the most effective and best performance among multiple abutments. This was achieved using network geometry plots and predictive interval plots. The network geometry plot was used to illustrate the network of interventions using multiple abutments (Ti, Al_2O_3, Au, and Zr). The nodes represent the competing treatments, and the edges represent the available direct comparisons between pairs of treatments. The predictive interval plot (PrI) and confidence interval plot (CrI) were evaluated. The predictive interval depicts where the estimate of a future study is expected to lie and indicates the most likely material to perform best in future clinical studies. The risk of bias among the abutment materials was estimated and rated as low risk, high risk, and unclear bias. The results of all direct and mixed comparisons were presented in forest plots. The latter were augmented with contours of effect magnitude based on multiples of the mean standard deviation of the included outcome (10%): 0–10%, clinically irrelevant effect; 10–20%, moderate effect; 20–30%, large effect; and >30%, very large effect. The surface under the cumulative ranking curves (SUCRA) was used to estimate the relative ranking of treatments using probabilities. The larger the SUCRA value, the better the rank of the treatment. Furthermore, multidimensional ranking (MDS rank) was used to rank the competing treatments based on the similarities and dissimilarities between any two treatments. MDS consists of multivariate techniques for analyzing proximity data and synthesizing the results on a 2-axis plot. It provides some insights into the differences in effect sizes among treatments, also accounting for the inconsistency in the network of interventions. The MDS rank graph would have a "0" value in the center, the left side would have negative values (less favorable outcome), and the right side would have positive values (more favorable outcome). All analyses were performed using Stata version 16 (StataCorp, College Station) by one author (SK), with the commands xtgee, metan, mvmeta, network, and the routines from Chaimani *et al*.[34]. A two-tailed *P*-value of 0.05 was considered significant for hypothesis testing.

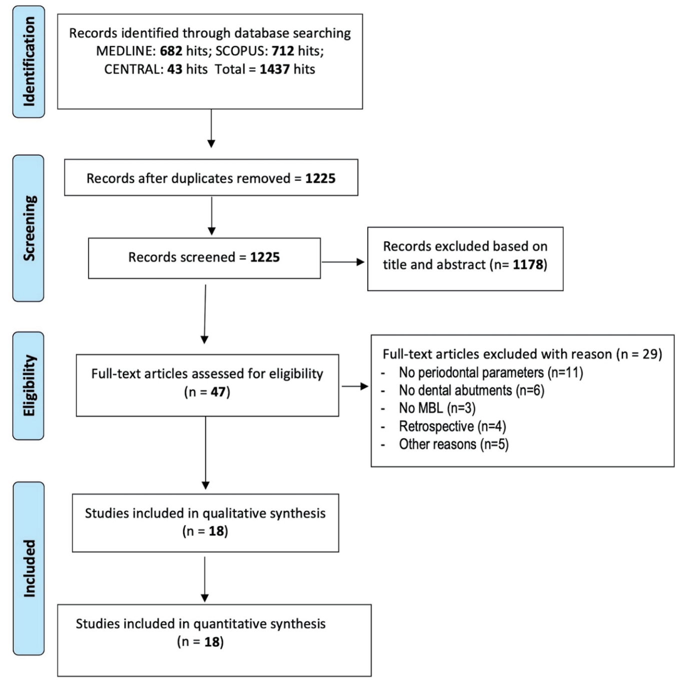


Fig. 1. Flowchart of the selection process

The number of studies selected for network meta-analysis was based on the different abutment materials used in each group. Information regarding the MD, SD, type of treatment, and the number of participants was extracted from clinical studies. Network meta-analysis was performed for each outcome, and in situations where only one study was identified for a given comparison and the same category of abutment material was used in both the control and test groups, the study was excluded from the analysis because there would be a network (geometry) disconnection and no further analysis would be possible. The reason for the exclusion of such studies was "data not comparable to other studies."

3. Results

3.1. Study selection

The flowchart of the selection process is presented in **Figure 1**. The search strategy identified a total of 1,437 studies. After screening based on title and abstract, 47 studies were identified as eligible.

After full-text evaluation, 29 studies were excluded and are reported in **Table S1**. The kappa value for the inter-reviewer agreement was 0.91, indicating a very good agreement. Eighteen articles were included[35–52], and the main characteristics are described in **Table 1**.

Nine studies were sponsored. Overall, 612 patients were treated, and 848 abutments were inserted. The follow-up duration ranged between 6 months and 7 years. A total of 343 titanium abutments were used as controls. Five studies did not report any information on complications at the prosthesis or abutment level. No control abutments failed; seven zirconia abutments failed in the test group.

3.2. Risk of bias

The risk of bias graph among the included studies is presented in **Figure S1**. Nine studies were assessed based on the Cochrane tool for assessing the risk of bias (**Figs. S1a and b**). We assessed eight studies (nine articles) based on the ROBINS tool for non-RCT studies (**Fig. S1c**). Four studies[37,40,44,45] were rated as low-risk of bias. All non-RCTs were rated as low risk of bias. Two studies[41,42] reported on different aspects and follow-ups of the same study.

3.3. Mean Bone Resorption (pairwise meta-analysis)

Based on nine studies[37–40,42,45,49–51], there was a significant reduction in bone resorption in groups using zirconia abutments than in those using titanium (0.20 mm; 95% CI [0.14–0.26], $P <$ 0.00001) (**Fig. S2a**). There was moderate heterogeneity among studies ($P = 0.003$). Subgroup analysis showed no difference in outcomes between RCTs and non-RCTs studies ($P = 0.97$), indicating that the study design did not affect bone resorption (**Fig. S2b**).

3.4. Probing depth (pairwise meta-analysis)

The analysis of the PD was divided into three categories (1 year, 3 years, 5–7 years) according to the follow-up time. After 1 year of follow-up, based on four studies[37,40,42,51], there was no significant difference in PD between zirconia and titanium abutments (0.08 mm; 95% CI [-0.23–0.40], $P = 0.61$) with a reduced heterogeneity (**Fig. 2a**).

At the 3-year follow-up, based on two studies[42,51], there was no significant difference between abutments (0.28 mm; 95% CI [-0.20–0.76], $P = 0.25$) with reduced heterogeneity (**Fig. 2b**).

At the 5–7-year follow-up, based on three studies[43,48,51], there was no significant difference between abutments (0.11 mm; 95% CI [-0.08–0.31], $P = 0.25$) with reduced heterogeneity (**Fig. 2c**).

3.5. Plaque Index (pairwise meta-analysis)

The analysis of the plaque index was conducted on three articles[47,48,50]. There was no significant difference in PI between zirconia and titanium abutments (-1.29; 95% CI [-3.75–1.17], $P = 0.30$) with high heterogeneity (**Fig. 3**).

3.6. Recession (Pairwise meta-analysis)

The analysis of the recession was conducted using five articles[37,40,42,43,51]. A sub-analysis was conducted considering the 1-year follow-up and the 3–7-year follow-up. The overall analysis showed no significant difference between zirconia and titanium abutments (-0.05 mm; 95% CI [-0.12–0.03], $P = 0.20$) with reduced heterogeneity (**Fig. 4a**).

The 1-year analysis was performed on three articles[37,40,42] and showed no significant difference between zirconia and titanium abutments (-0.05 mm; 95% CI [-0.12–0.02], $P = 0.17$) with reduced heterogeneity (**Fig. 4b**).

Similar results were obtained by analyzing the 3–7 years period. The analysis was conducted on three articles[42,43,51] and showed no significant difference between zirconia and titanium abutments (0.04 mm, 95% CI [-0.24–0.32], $P = 0.79$) with reduced heterogeneity (**Fig. 4c**).

3.7. Network Geometry Plot

The network geometry plot for different types of abutments for PI, REC, BOP, and PD outcomes is reported in **Figure 5a**. In the network geometry plot, the network nodes demonstrate the number of subjects that were included in respective material groups. The thickness of the yellow lines is proportional to the number of comparisons included for analysis. The numbers of participants and comparisons were higher between titanium and zirconia abutments. The risk of bias is highlighted in a different color (yellow: moderate risk of bias; **Fig. 5b**).

3.8. Network Geometry Plot for Marginal Bone Loss (MBL) Outcome

Titanium and zirconia abutments were most frequently compared and involved more participants than the other groups. The risk of bias is highlighted and indicated by a different color of the lines in the network for each comparison (**Fig. 6a**). There was a high risk of bias between titanium and alumina (red line; **Fig. 6b**).

3.9. Predictive Interval Plots

Predictive interval plots are reported in **Figures 7a–e**. Zirconia and gold abutments performed better than other materials regarding MBL outcome. It was based on the intervals predicted for different abutment materials included in the analysis.

3.10. Surface under the cumulative ranking curves (SUCRA)

Zirconia abutments showed SUCRA scores of 83.3% in PI, 87.0% in BOP, and 65.0% in PD outcome, suggesting that zirconia abutments performed better than titanium and alumina abutments (**Fig. 8**). More studies are needed for gold abutments, as a comparison was made only in relation to MBL.

3.11. Multidimensional Scale Ranking (MDS)

Materials showing the most dissimilar result as compared to the competing abutments, according to a multidimensional scale (absolute value of the horizontal axis in the plots of **Figure 9**), were zirconia for BOP, PD, and REC, and alumina for PI and MBL. In the REC plot, titanium appeared to be as dissimilar to zirconia. The ranking of the abutments is represented on the vertical axis for each outcome.

Table 1. Main characteristics of the included studies

Authors	Year	Country	Sponsor	Smokers incl. Y/N	Age (Years)	Subjects (N)	Abutments (N)	Abutment control (N)	Material (test)	Mean MBL (months) control	Mean MBL (months) test	Complications control	Complications test
Koller M, Steyer E, Theisen K, Stagnell S, Jakse N, Payer M.	2020	Austria	Yes	No	46	22	31	15	Zir	30 months: 0.92 80 months: 1.17	30 months: 1.51 80 months: 1.38	0	0
Bharate V, Kumar Y, Koli D, Pruthi G, Jain V.	2020	India	No	No	20–45	11	22	11	Zir	0–3 months: 0.32 3–12 months: 0.346 0–12 months: 0.621	0–3 months: 0.202 3–12 months: 0.285 0–12 months: 0.487		
de Oliveira Silva TS, de Freitas AR, de Albuquerque RF, Pedrazzi V, Ribeiro RF, do Nascimento C.	2020	Brazil	No	ND	45.5	20	20	10	Zir	baseline-1 year: -0.39 1–2 years: -0.26 2–3 years: -0.34	baseline-1 year: -0.30 1–2 years: -0.34 2–3 years: -0.12		
de Freitas AR, Silva TSO, Ribeiro RF, de Albuquerque Junior RF, Pedrazzi V, do Nascimento C.	2018	Brazil	No	ND	45.5	20	20	10	Zir	6 months: 1.25	6 months: 0.92	0	0
Bösch A, Jung RE, Sailer I, Goran B, Hämmerle CH, Thoma DS.	2018	Switzerland	Yes	ND	43.7+-13,8	29	29	16	Zir	-0,28	-0,05	0	1 crown chipping of veneering ceramic
Baldini N, D'Elia C, Clementini M, Carrillo de Albornoz A, Sanz M, De Sanctis M.	2016	Italy	Yes	ND	test 54.1 control 57.7	24	22	12	Zir	mean mesial bone loss: 1 month: 1.41 12 months: 1.98 mean distal bone loss: 1 month: 1.43 12 months: 1.74	mean mesial bone loss: 1 month: 1.54 12 months: 1.11 mean distal bone loss: 1 month: 1.55 12 months: 1.16	0	0
Nascimento Cd, Pita MS, Santos Ede S, Monesi N, Pedrazzi V, Albuquerque Junior RF, Ribeiro RF.	2016	Brazil	No	ND	45.5	20	20	10	Zir	0–3 months: 0.93 3–6 months: 0.32	0–3 months: 0.78 3–6 months: 0.14		
Fenner N, Hämmerle CH, Sailer I, Jung RE.	2016	Switzerland	No	ND	48	36	28	15	Alumina	mesial: 2.1 distal: 2.4	mesial: 2.2 distal: 2.8	2 chipping	1 chipping
Payer M, Heschl A, Koller M, Arnetzl G, Lorenzoni M, Jakse N.	2015	Austria	Yes	No	46	22	31	15	Zir	baseline: 0.16 6 months: 0.4 12 months: 0.88 18 months: 1.15 24 months: 1.43	baseline:0.10 6 months: 0.67 12 months: 1.16 18 months: 1.2 24 months: 1.48	0	0
Ferrari M, Cagidiaco MC, Garcia-Godoy F, Goracci C, Cairo F.	2015	Italy	Yes	yes <10 die	55.60+-11.19	47	97	nD	Zir, Zir Nitride	-0,42	Zir -0,57 Zir Nitride -0,48		
Carrillo de Albornoz A, Vignoletti F, Ferrantino L, Cárdenas E, De Sanctis M, Sanz M.	2014	Spain	No	ND	test 51.6 control 51.8	30	26	14	Zir	1 month mesial: -1.52 distal:-1.73 12 months mesial:-1.97 distal:-1.73	1 month mesial: -1.60 distal:-1.60 12 months mesial:-1.66 distal:-1.55	0	2 abutments fractured
Zembic A, Bösch A, Jung RE, Hämmerle CH, Sailer I.	2013	Switzerland	Yes	Yes	41.3+-18.0	22	28	10	Zir	baseline: mesial: 2.0 distal: 2.0 1 year: mesial: 2.2 distal: 2.3 3 years: mesial: 2.0 distal: 2.1 5 years: mesial: 2.0 distal: 1.9	baseline: mesial: 1.5 distal: 1.5 1 year: mesial: 1.4 distal: 1.5 3 years: mesial: 1.7 distal: 1.6 5 years: mesial: 1.8 distal: 2.0	3 crowns chipping	0

Table 1. ***Continued***

Authors	Year	Country	Sponsor	Smokers incl. Y/N	Age (Years)	Subjects (N)	Abutments (N)	Abutment control (N)	Material (test)	Mean MBL (months) control	Mean MBL (months) test	Complications control	Complications test
Hosseini M, Worsaae N, Schiødt M, Gotfredsen K.	2013	Denmark	Yes	ND	27.9 (SD 9.3)	59	98	21	Zir, Gold alloy	3 years: 0.36	Zir: 0.60 Gold Alloy: 0.52	2 crown loss retention (3 years)	1 minor chipping (baseline), 1 fracture of veneering (3 years); 1 unacceptable margin (baseline); 1 unacceptable margin (3 years)
Lops D, Bressan E, Chiapasco M, Rossi A, Romeo E.	2013	Italy	No	Yes <15die	67	85	81	44	Zir	baseline: 0.2 5 years: 0.5	baseline: 0.1 5 years: 0.4	3 veneer chipping crown	4 minor chipping veneering ceramic crown
Hosseini M, Worsaae N, Schiodt M, Gotfredsen K. A	2011	Denmark	Yes	ND	28.1 mean (SD 9.2)	36	75	35	Zir, Gold	baseline: 0.33 12 months: 0.43	baseline: 0.58 12 months: 0.66	1 chipping 1 loss of retention	0
Zembic A, Sailer I, Jung RE, Hämmerle CH.	2009	Switzerland	Yes	yes	41.3	22	28	10	Zir	baseline: mesial: 2.0 distal: 2.0 1 year: mesial: 2.2 distal: 2.3 3 years: mesial: 2.0 distal: 2.1	baseline: mesial: 1.5 distal: 1.5 1 year: mesial: 1.4 distal: 1.5 3 years: mesial: 1.7 distal: 1.6	2 crown minor chipping	0
Andersson B, Glauser R, Maglione M, Taylor A.	2003	Sweden	No	ND	53	32	103	50	Alumina	0.4	0.3	4 abutment and 1 FDP Withdraw	
Andersson B, Taylor A, Lang BR, Scheller H, Schärer P, Sorensen JA, Tarnow D.	2001	Sweden	No	ND	group A: 37 group B: 32	75	89	45	Alumina	group A: 1 year: 0.0 group B: 1 year: 0.3 3 years: -0.1	Group A: 1 year: 0.1 Group B: 1 year: 0.1 3 years: 0.1		

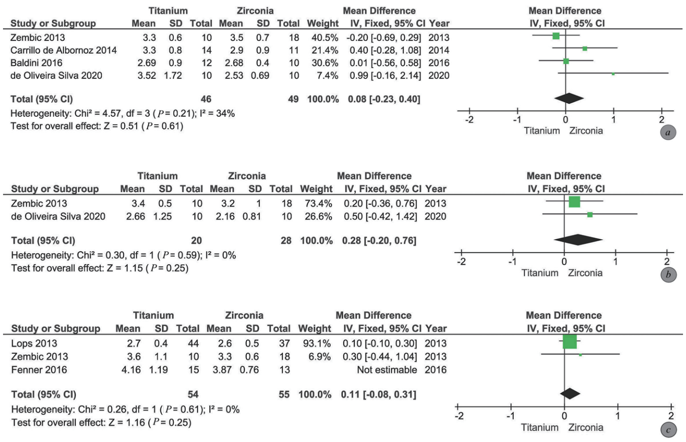


Fig. 2. Pairwise meta-analysis: probing depth. (a) The overall results. (b) The 3-year follow-up results. (c) The 5–7-year follow-up results.

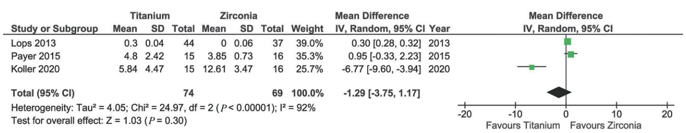


Fig. 3. Pairwise meta-analysis: plaque index

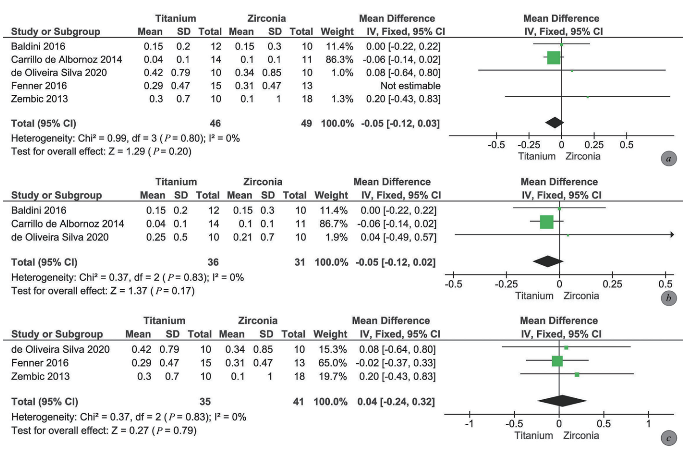


Fig. 4. Pairwise meta-analysis: recession. (a) The overall results. (b) The 1-year follow-up results. (c) The 3–7-year follow-up results.

4. Discussion

Previous reviews have attempted to address the topic analyzed in this review. Hu *et al.*[53] sought to ascertain the survival rates of various abutments, MBLs, and peri-implant soft tissue. Fourteen RCTs and nine non-RCTs were found eligible. The authors concluded that there were no significant differences in terms of survival rate, MBL, and peri-implant soft tissue discoloration among titanium (Ti), zirconia (Zr), gold (Au), and alumina (Al) abutments. Furthermore, the Ti abutment had the greatest cumulative ranking of survival rate (97.9%); the Al abutment had the lowest marginal bone loss (81.4%); and the Zr abutment had the least discoloration of peri-implant soft tissue (84.8%).

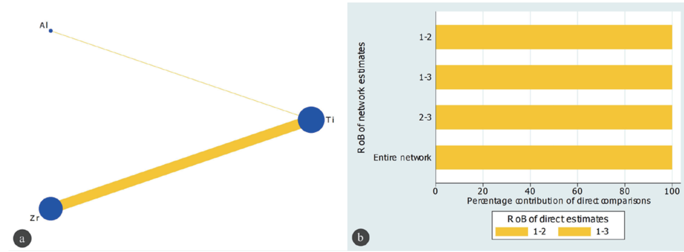


Fig. 5. Network meta-analysis results for plaque index (PI), recession (REC), bleeding on probing (BOP), and probing depth (PD). (a) Network geometry plot for different types of abutments for PI, REC, BOP, and PD outcomes. Ti: titanium, Al: alumina (Al_2O_3), and Zr: zirconia. (b) Risk of bias (RoB) between each abutment's comparison for PI, PD, BOP, and REC outcomes. There is no high risk of bias in any comparison of abutments. 1. Ti; 2. Al; 3. Zr.

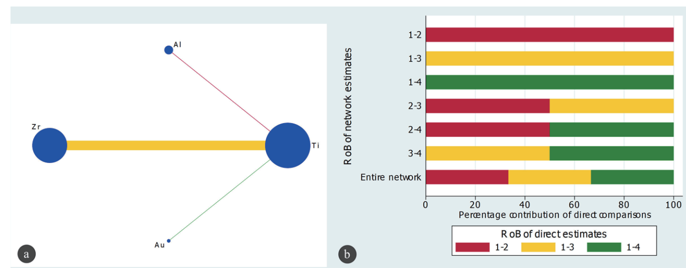


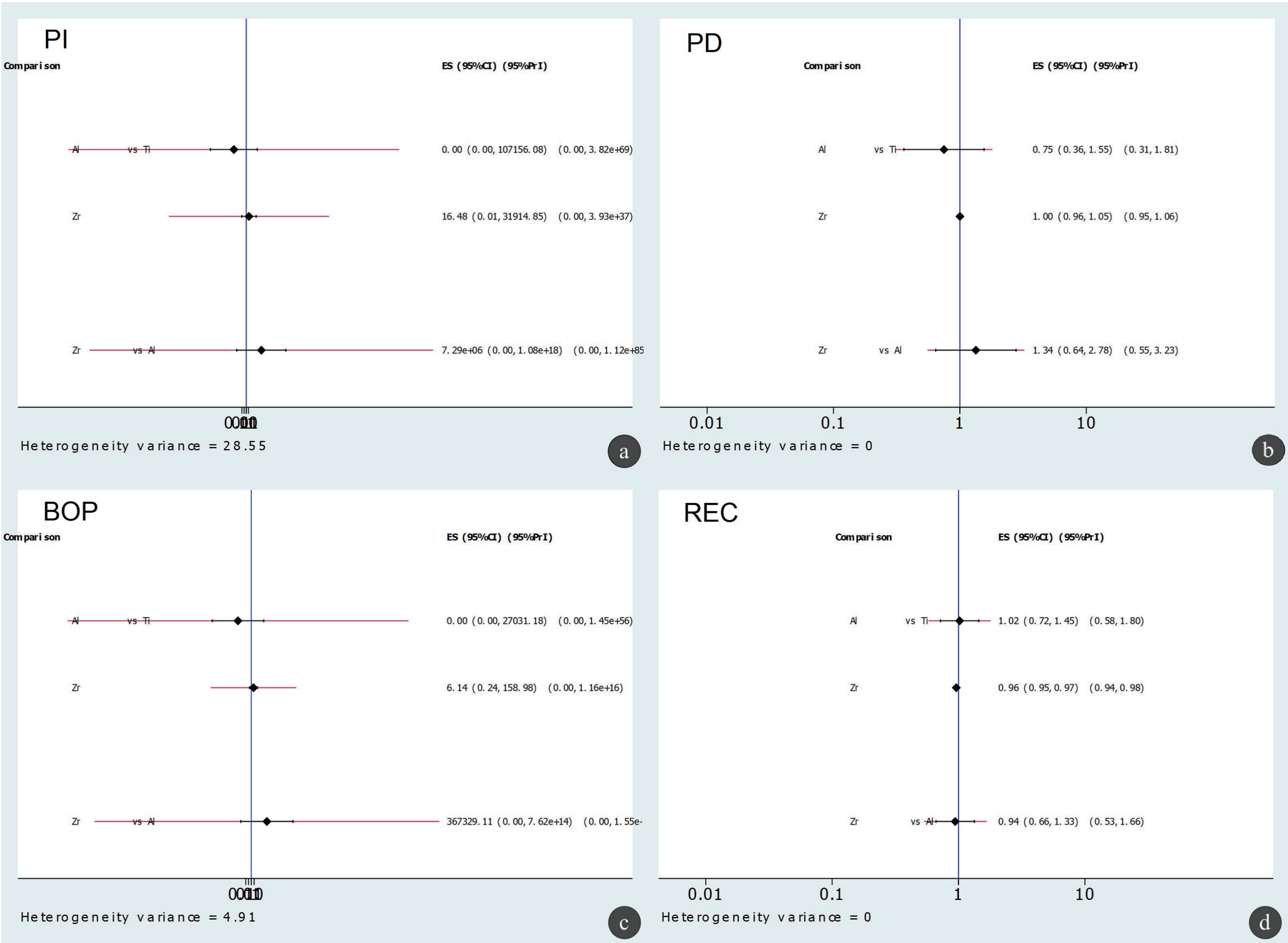
Fig. 6. Network meta-analysis results for marginal bone loss (MBL). (a) Network geometry plot for MBL outcome. The network nodes demonstrate the number of subjects that were included in the respective material groups. Thicker lines were proportional to the number of comparisons included for analysis. Titanium (Ti) and zirconia (Zr) abutments were most frequently compared and involved more subjects in both groups. (b) Risk of bias (RoB) among each comparison of abutments for MBL outcome. There was a high risk of bias in the titanium and alumina comparison. 1. Ti; 2. Alumina (Al_2O_3); 3. Zr; 4. Gold.

Our review aimed to evaluate the abutment materials by analyzing their effect on hard and soft tissues. Five outcomes, i.e., MBL, REC, PI, PD, and BOP, were analyzed and illustrated through network geometry plots, predictive interval plots, SUCRA ranking, and multidimensional scale ranking. We ranked the best-performing abutment type based on SUCRA and multidimensional scale ranking. Furthermore, we made a subgroup analysis for different sets of studies included (**Fig. S2b**).

Regarding bone preservation, zirconia abutments performed significantly better than titanium abutments at the marginal bone level. However, the clinical significance of this data should be questioned because the MD in MBL was as low as 0.2 mm (**Fig. 3**).

This information represents new data compared with the results of a previous systematic review by Sanz-Sanchez *et al.*[54], who failed to find any difference in terms of MBL between zirconia and titanium. This might be due to the higher number of studies included in this review.

This different behavior might be related to better hard and soft tissue cell stabilization on the zirconia surface, as demonstrated by Bergeman *et al.*[55]. Surface roughness may directly influence cell response, and a titanium-modified surface can increase soft tissue adhesion[17]. Titanium abutments usually present a polished



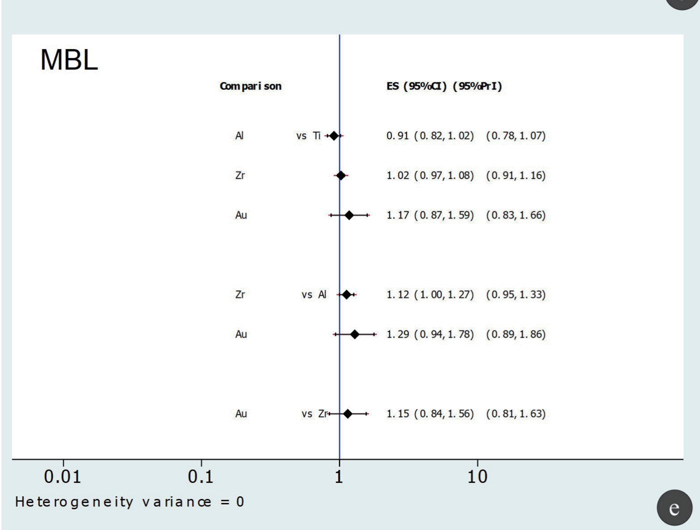


Fig. 7. Predictive interval plots (Ti: titanium, Al: alumina (Al_2O_3), Zr: zirconia, Au: gold). (a) Predictive interval plot for plaque index (PI) outcome. Zr and Al perform better. (b) Predictive interval plot for probing depth (PD) outcome. Zr and Al perform better. (c) Predictive interval plot for bleeding on probing (BOP) outcome. Zr and Al perform better. (d) Predictive interval plot for recession (REC) outcome. Ti abutments perform better. (e) Predictive interval plot for marginal bone loss (MBL) outcome. Zr and Au perform better.

surface at the mucosal-bone interface. However, sintered zirconia abutments often show a rougher surface due to their preparation processes, which may increase soft tissue adhesion[56]. Paul *et al.* reported the same fibroblast behavior when comparing zirconia and tridimensional-designed titanium[57].

However, this supposition contrasts with the outcomes reported by Pandoleon *et al.*[58], who failed to find any difference in terms of cell adherence and viability between zirconia, alumina, disilicate, and titanium, irrespective of the external surface roughness. Data from Pandoleon *et al.*[58] confirmed the results of Welander *et al.*[59] on a dog model, which highlighted similar soft tissue morphogenesis between titanium and zirconia[59].

Focusing on periodontal parameters, the outcomes of the meta-analysis failed to report any significant difference in plaque adhesion and inflammatory response. This is consistent with data reported by Sanz-Sanchez *et al.*[54].

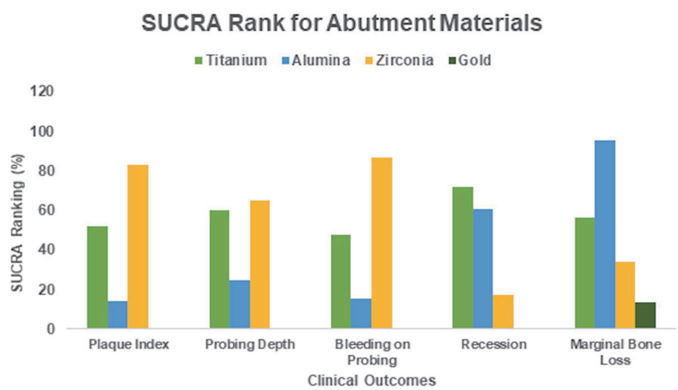


Fig. 8. Surface under the cumulative ranking curves (SUCRA) ranking for different comparisons of abutment materials with varying outcomes. Zirconia ranked highest and performed best in the majority of outcomes, followed by titanium implant abutments. SUCRA, surface under the cumulative ranking curves.

Meta-analysis of the gingival recession highlighted, with reduced heterogeneity, the absence of significant differences among zirconia and titanium abutments, both on short and long follow-up intervals, in terms of PD and recession values.

Soft tissue PD is influenced by surgical factors (tridimensional implant position), anatomical factors (thickness of gingival phenotype), and abutment soft tissue integration. These variables were not reported in the studies included, and consequently, they were not critically analyzed. However, it can be speculated that the structural characteristics of the abutment bulk material cannot influence PD.

Soft tissue recession might be the expression of longitudinal soft tissue adaptation to the abutment[60], and it is influenced by several factors, including the compression of the mucosa due to the abutment geometry, together with the position of the implant and the soft tissue phenotype[61]. Although a recent systematic review[62] suggests that narrow abutments fail to show any difference, compared to wider abutments, in terms of soft tissue health and esthetics, the macro geometry of the abutment may result in compression or decompression of the connective component of the supracrestal tissue attachment. While compression often leads to an apical repositioning of the mucosal complex, decompression of the soft tissues often produces coronal displacement. This effect might overcome the influence of the abutment material characteristics and explain why the bulk material of the abutment resulted in an insignificant effect.

Under SUCRA rankings, zirconia was ranked higher and performed best among the majority of the outcomes, followed by titanium abutments. However, alumina ranked higher and performed best in the recession and MBL outcomes. These differences might be due to the data available for the analysis. Pairwise meta-analysis illustrates the comparisons between pairs of interventions for a specific condition and in a specific setting. However, there will be several options for interventions and materials available for any given clinical situation. Conversely, NMA includes all possible interventions and illustrates their comparative effectiveness and potential for harm.

Chaimani *et al.*[34] suggested using a multidimensional scaling technique to visualize the level of similarity in the ranking between interventions. Based on our results, on a multidimensional scale, zirconia and alumina abutments appeared to be the most dissimilar materials compared to the others, positioned far apart for specific outcomes. In general, titanium abutments demonstrated greater similarity, positioned mostly closer to other materials on the MDS scale. This is a peculiar outcome since zirconia and alumina are both ceramic materials sharing similar characteristics such as high biocompatibility, rigidity, and low plaque adhesion.

Articles included in the present analysis failed to consider the effect of abutment surface energy, which correlates with hydrophilicity and is negatively affected by the presence of contaminants on the

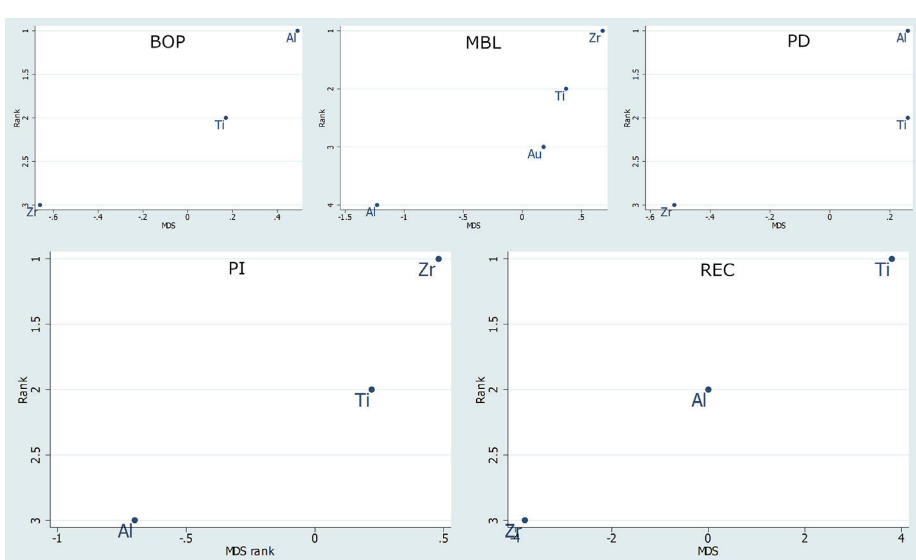


Fig. 9. Multidimensional Scale Ranking (MDS Rank) illustrating the most dissimilar material in each outcome. The multidimensional ranking method in network meta-analysis estimates the relative ranking for different competing treatments. BOP: bleeding on probing, MBL: marginal bone loss, PD: probing depth, PI: plaque index, REC: recession, Ti: titanium, Al: alumina, Zr: zirconia, Au: gold.

surface. An increased surface wettability may result in a biological advantage both from the quantitative (higher number of adherent cells) and qualitative (flat *vs.* spread arrangement) points of view[63]. In the clinic, this advantage results in stronger fibroblast adhesion even in the initial stages of the treatment, as evidenced by the presence of pseudopodia, and improved clinical parameters[64].

A predictive interval plot gives information on different abutment materials that would most likely perform best in future studies. This would provide an expected value of information to clinicians to choose materials in future clinical studies and develop evidence that would enable recommendations on the choice of material for specific clinical indications. This would help to manage the research waste and the cost of the experiments, the dentists, and the patients.

This review has some limitations. First, there is heterogeneity among the included studies, particularly in the MBL and PI analyses, regarding the study's design and clinical procedures. Some of the included studies were primarily designed to assess esthetics, not bone loss. In these studies, titanium abutments in combination with metal-ceramic crowns and titanium implants were compared with "non-titanium" abutments in combination with all-ceramic crowns and zirconia implants; in other studies, titanium abutments were placed in the posterior area while zirconia abutments were placed in the anterior area. For example, Andersson *et al.*[35] compared two materials, CerAdapt (test) ceramic abutments, and CeraOne (control) titanium abutments, and divided them into two groups, i.e., the material was separated into two groups: 69 (34 test, 35 control) abutments or crowns from all involved clinics were followed for one year in group A, and 20 (10 test, 10 control) abutments or crowns from one of the clinics were followed for 3 years in group B.

Furthermore, the follow-up period varied between 6 months and 7 years in the different studies. A subgrouping, merging the similar follow-up time data, was done when possible. Additionally, the limitations of the SUCRA ranking should be considered before making any decisions[65].

There were not enough studies to grade the quality of evidence among different comparisons of the dental abutment materials in the network meta-analysis. Therefore, the recommendation for the best choice of abutment for any clinical outcomes would be difficult. Although zirconia, followed by titanium, was found to be most effective in the majority of soft tissue clinical outcomes, more randomized clinical trials with different comparisons between abutment materials are required.

Finally, not only the abutment material but also the implant material varied among the included studies. While all the control titanium abutments were screwed on titanium implants, zirconia abutments were screwed on zirconia implants in two test groups.

Additional limitations of this review include the lack of clinical subgrouping (e.g., according to the initial soft tissue quality and dimension), which could provide reliable data minimizing the heterogeneity, though further data fragmentation may prevent aggregation in a network, or even pairwise, meta-analysis.

It must be considered that clinicians cannot choose abutment material based on the parameter of soft tissue response, and other aspects (i.e., mechanical strength, fracture resistance) are also important factors for choosing abutment material.

5. Conclusions

Within the limits of this study, zirconia abutments seem a viable alternative to the use of classical titanium abutments. More clinical studies focused on comparing abutment materials are needed to obtain more robust conclusions.

Conflict of interest statement

The authors declare no conflict of interest.

References

[1] Moraschini V, Poubel LAC, Ferreira VF, Barboza ESP. Evaluation of survival and success rates of dental implants reported in longitudinal studies with a follow-up period of at least 10 years: a systematic review. Int J Oral Maxillofac Surg. 2015;44:377–88. https://doi.org/10.1016/j.ijom.2014.10.023, PMID:25467739

[2] Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. Clin Oral Implants Res. 2012;23(suppl 6):2–21. https://doi.org/10.1111/j.1600-0501.2012.02547.x, PMID:23062124

[3] Tolstunov L. Dental implant success-failure analysis: a concept of implant vulnerability. Implant Dent. 2006;15:341–6. https://doi.org/10.1097/01.id.0000239333.24384.5d, PMID:17172950

[4] Quirynen M, De Soete M, Van Steenberghe D. Infectious risks for oral implants: a review of the literature. Clin Oral Implants Res. 2002;13:1–19. https://doi.org/10.1034/j.1600-0501.2002.130101.x, PMID:12005139

[5] Menini M, Setti P, Pera P, Pera F, Pesce P. Peri-implant Tissue Health and Bone Resorption in Patients with Immediately Loaded, Implant-Supported, Full-Arch Prostheses. Int J Prosthodont. 2018;31:327–33. https://doi.org/10.11607/ijp.5567, PMID:29953561

[6] Berglundh T, Lindhe J, Ericsson I, Marinello CP, Liljenberg B, Thornsen P. The soft tissue barrier at implants and teeth. Clin Oral Implants Res. 1991;2:81–90. https://doi.org/10.1034/j.1600-0501.1991.020206.x, PMID:1809403

[7] Atsuta I, Ayukawa Y, Kondo R, Oshiro W, Matsuura Y, Furuhashi A, *et al.* Soft tissue sealing around dental implants based on histological interpretation. J Prosthodont Res. 2016;60:3–11. https://doi.org/10.1016/j.jpor.2015.07.001, PMID:26725967

[8] Linkevicius T, Apse P. Influence of abutment material on stability of peri-implant tissues: a systematic review. Int J Oral Maxillofac Implants. 2008;23:449–56. PMID:18700367

[9] Menini M, Dellepiane E, Chvartszaid D, Baldi D, Schiavetti I, Pera P. Influence of Different Surface Characteristics on Peri-implant Tissue Behavior: A Six-Year Prospective Report. Int J Prosthodont. 2015;28:389–95. https://doi.org/10.11607/ijp.4066, PMID:26218023

[10] Baldi D, Menini M, Pera F, Ravera G, Pera P. Plaque accumulation on exposed titanium surfaces and peri-implant tissue behavior. A preliminary 1-year clinical study. Int J Prosthodont. 2009;22:447–55. PMID:20095192

[11] Delucchi F, Pozzetti E, Bagnasco F, Pesce P, Baldi D, Pera F, *et al.* Peri-Implant Tissue Behaviour Next to Different Titanium Surfaces: 16-Year Post-Trial Follow-Up. Appl Sci (Basel). 2021;11:9625. https://doi.org/10.3390/app11209625

[12] Menini M, Delucchi F, Bagnasco F, Pera F, Di Tullio N, Pesce P. Analysis of the Subgingival Microbiota in Implant-Supported Full-Arch Rehabilitations. Dent J (Basel). 2020;8:104. https://doi.org/10.3390/dj8030104, PMID:32899493

[13] Alovisi M, Carossa M, Mandras N, Roana J, Costalonga M, Cavallo L, *et al.* Disinfection and Biocompatibility of Titanium Surfaces Treated with Glycine Powder Airflow and Triple Antibiotic Mixture: An In Vitro Study. Materials (Basel). 2022;15:4850. https://doi.org/10.3390/ma15144850, PMID:35888317

[14] Canullo L, Annunziata M, Pesce P, Tommasato G, Nastri L, Guida L. Influence of abutment material and modifications on peri-implant soft-tissue attachment: A systematic review and meta-analysis of histological animal studies. J Prosthet Dent. 2021;125:426–36. https://doi.org/10.1016/j.prosdent.2020.01.025, PMID:32197823

[15] Corvino E, Pesce P, Mura R, Marcano E, Canullo L. Influence of Modified Titanium Abutment Surface on Peri-implant Soft Tissue Behavior: A Systematic Review of In Vitro Studies. Int J Oral Maxillofac Implants. 2020;35:503–19. https://doi.org/10.11607/jomi.8110, PMID:32406646

[16] Pesce P, Menini M, Santori G, Giovanni ED, Bagnasco F, Canullo L. Photo and Plasma Activation of Dental Implant Titanium Surfaces. A Systematic Review with Meta-Analysis of Pre-Clinical Studies. J Clin Med. 2020;9:2817. https://doi.org/10.3390/jcm9092817, PMID:32878146

[17] Pesce P, Menini M, Tommasato G, Patini R, Canullo L. Influence of modified titanium abutment surface on peri-implant soft tissue behaviour: A systematic review of histological findings. Int J Oral Implantol (Berl). 2019;12:419–29. PMID:31781697

[18] Conserva E, Lanuti A, Menini M. Cell behavior related to implant surfaces with different microstructure and chemical composition: an in vitro analysis. Int J Oral Maxillofac Implants. 2010;25:1099–107. PMID:21197485

[19] Conserva E, Menini M, Ravera G, Pera P. The role of surface implant treatments on the biological behavior of SaOS-2 osteoblast-like cells. An *in vitro* comparative study. Clin Oral Implants Res. 2013;24:880–9. https://doi.org/10.1111/j.1600-0501.2011.02397.x, PMID:22251013

[20] Canullo L, Menini M, Santori G, Rakic M, Sculean A, Pesce P. Titanium abutment surface modifications and peri-implant tissue behavior: a systematic review and meta-analysis. Clin Oral Investig. 2020;24:1113–24. https://doi.org/10.1007/s00784-020-03210-x, PMID:31955269

[21] Andersson B, Odman P, Lindvall AM, Lithner B. Single-tooth restorations supported by osseointegrated implants: results and experiences from a prospective study after 2 to 3 years. Int J Oral Maxillofac Implants. 1995;10:702–11. PMID:8530173

[22] Sailer I, Philipp A, Zembic A, Pjetursson BE, Hämmerle CHF, Zwahlen M. A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. Clin Oral Implants Res. 2009;20(suppl 4):4–31. https://doi.org/10.1111/j.1600-0501.2009.01787.x, PMID:19663946

[23] Park SE, Da Silva JD, Weber HP, Ishikawa-Nagai S. Optical phenomenon of peri-implant soft tissue. Part I. Spectrophotometric assessment of natural tooth gingiva and peri-implant mucosa. Clin Oral Implants Res. 2007;18:569–74. https://doi.org/10.1111/j.1600-0501.2007.01391.x, PMID:17655713

[24] Prestipino V, Ingber A. Esthetic high-strength implant abutments. Part I. J Esthet Restor Dent. 1993;5:29–36. https://doi.org/10.1111/j.1708-8240.1993.tb00741.x, PMID:8507510

[25] Bressan E, Paniz G, Lops D, Corazza B, Romeo E, Favero G. Influence of abutment material on the gingival color of implant-supported all-ceramic restorations: a prospective multicenter study. Clin Oral Implants Res. 2011;22:631–7. https://doi.org/10.1111/j.1600-0501.2010.02008.x, PMID:21070378

[26] Canullo L. Clinical outcome study of customized zirconia abutments for single-implant restorations. Int J Prosthodont. 2007;20:489–93. PMID:17944337

[27] Manicone PF, Iommetti PR, Raffaelli L, Paolantonio M, Rossi G, Berardi D, *et al.* Biological considerations on the use of zirconia for dental devices. Int J Immunopathol Pharmacol. 2007;20(suppl 1):9–12. https://doi.org/10.1177/039463200702001s03, PMID:17897494

[28] Rimondini L, Cerroni L, Carrassi A, Torricelli P. Bacterial colonization of zirconia ceramic surfaces: an in vitro and in vivo study. Int J Oral Maxillofac Implants. 2002;17:793–8. PMID:12507238

[29] van Brakel R, Cune MS, van Winkelhoff AJ, de Putter C, Verhoeven JW, van der Reijden W. Early bacterial colonization and soft tissue health around zirconia and titanium abutments: an in vivo study in man. Clin Oral Implants Res. 2011;22:571–7. https://doi.org/10.1111/j.1600-0501.2010.02005.x, PMID:21054554

[30] Abrahamsson I, Berglundh T, Glantz PO, Lindhe J. The mucosal attachment at different abutments. An experimental study in dogs. J Clin Periodontol. 1998;25:721–7. https://doi.org/10.1111/j.1600-051X.1998.tb02513.x, PMID:9763327

[31] Stone PW. Popping the (PICO) question in research and evidence-based practice. Appl Nurs Res. 2002;15:197–8. https://doi.org/10.1053/apnr.2002.34181, PMID:12173172

[32] Gavaghan DJ, Moore AR, McQuay HJ. An evaluation of homogeneity tests in meta-analyses in pain using simulations of individual patient data. Pain. 2000;85:415–24. https://doi.org/10.1016/S0304-3959(99)00302-4, PMID:10781914

[33] IntHout J, Ioannidis JPA, Borm GF, Goeman JJ. Small studies are more heterogeneous than large ones: a meta-meta-analysis. J Clin Epidemiol. 2015;68:860–9. https://doi.org/10.1016/j.jclinepi.2015.03.017, PMID:25959635

[34] Chaimani A, Higgins JPT, Mavridis D, Spyridonos P, Salanti G. Graphical tools for network meta-analysis in STATA. PLoS One. 2013;8:e76654. https://doi.org/10.1371/journal.pone.0076654, PMID:24098547

[35] Andersson B, Glauser R, Maglione M, Taylor A. Ceramic implant abutments for short-span FPDs: a prospective 5-year multicenter study. Int J Prosthodont. 2003;16:640–6. PMID:14714845

[36] Andersson B, Taylor A, Lang BR, Scheller H, Schärer P, Sorensen JA, *et al.* Alumina ceramic implant abutments used for single-tooth replacement: a prospective 1- to 3-year multicenter study. Int J Prosthodont. 2001;14:432–8. PMID:12066638

[37] Baldini N, D'Elia C, Clementini M, de Albornoz A, Sanz M, De Sanctis M. Esthetic Outcomes of Single-Tooth Implant-Supported Restorations Using Metal-Ceramic Restorations with Zirconia or Titanium Abutments: A Randomized Controlled Clinical Study. Int J Periodontics Restorative Dent. 2016;36:e59–66. https://doi.org/10.11607/prd.2599, PMID:27333019

[38] Bharate V, Kumar Y, Koli D, Pruthi G, Jain V. Effect of different abutment materials (zirconia or titanium) on the crestal bone height in 1 year. J Oral Biol Craniofac Res. 2020;10:372–4. https://doi.org/10.1016/j.jobcr.2019.10.001, PMID:31737476

[39] Bösch A, Jung R, Sailer I, Goran B, Hans C, Thoma D. Single-Tooth Replacement Using Dental Implants Supporting All-Ceramic and Metal-Based Reconstructions: Results at 18 Months of Loading. Int J Periodontics Restorative Dent. 2018;38:173–9. https://doi.org/10.11607/prd.2846, PMID:29447309

[40] Carrillo de Albornoz A, Vignoletti F, Ferrantino L, Cárdenas E, De Sanctis M, Sanz M. A randomized trial on the aesthetic outcomes of implant-supported restorations with zirconia or titanium abutments. J Clin Periodontol. 2014;41:1161–9. https://doi.org/10.1111/jcpe.12312, PMID:25244317

[41] de Freitas AR, Silva TSO, Ribeiro RF, de Albuquerque Junior RF, Pedrazzi V, do Nascimento C. Oral bacterial colonization on dental implants restored with titanium or zirconia abutments: 6-month follow-up. Clin Oral Investig. 2018;22:2335–43. https://doi.org/10.1007/s00784-018-2334-0, PMID:29349504

[42] Oliveira Silva TS, Freitas AR, Albuquerque RF, Pedrazzi V, Ribeiro RF, Nascimento C. A 3-year longitudinal prospective study assessing microbial profile and clinical outcomes of single-unit cement-retained implant restorations: zirconia versus titanium abutments. Clin Implant Dent Relat Res. 2020;22:301–10. https://doi.org/10.1111/cid.12888, PMID:32026617

[43] Fenner N, Hämmerle CHF, Sailer I, Jung RE. Long-term clinical, technical, and esthetic outcomes of all-ceramic vs. titanium abutments on implant supporting single-tooth reconstructions after at least 5 years. Clin Oral Implants Res. 2016;27:716–23. https://doi.org/10.1111/clr.12654, PMID:26086947

[44] Ferrari M, Cagidiaco MC, Garcia-Godoy F, Goracci C, Cairo F. Effect of different prosthetic abutments on peri-implant soft tissue. A randomized controlled clinical trial. Am J Dent. 2015;28:85–9. PMID:26087573

[45] Hosseini M, Worsaae N, Schiodt M, Gotfredsen K. A 1-year randomised controlled trial comparing zirconia versus metal-ceramic implant supported single-tooth restorations. Eur J Oral Implantology. 2011;4:347–61. PMID:22282731

[46] Hosseini M, Worsaae N, Schiødt M, Gotfredsen K. A 3-year prospective study of implant-supported, single-tooth restorations of all-ceramic and metal-ceramic materials in patients with tooth agenesis. Clin Oral Implants Res. 2013;24:1078–87. https://doi.org/10.1111/j.1600-0501.2012.02514.x, PMID:22708959

[47] Koller M, Steyer E, Theisen K, Stagnell S, Jakse N, Payer M. Two-piece zirconia versus titanium implants after 80 months: clinical outcomes from a prospective randomized pilot trial. Clin Oral Implants Res. 2020;31:388–96. https://doi.org/10.1111/clr.13576, PMID:31944420

[48] Lops D, Bressan E, Chiapasco M, Rossi A, Romeo E. Zirconia and titanium implant abutments for single-tooth implant prostheses after 5 years of function in posterior regions. Int J Oral Maxillofac Implants. 2013;28:281–7. https://doi.org/10.11607/jomi.2668, PMID:23377075

[49] do Nascimento C, Pita MS, Santos ES, Monesi N, Pedrazzi V, de Albuquerque Junior RF, *et al.* Microbiome of titanium and zirconia dental implants abutments. Dent Mater. 2016;32:93–101. https://doi.org/10.1016/j.dental.2015.10.014, PMID:26616687

[50] Payer M, Heschl A, Koller M, Arnetzl G, Lorenzoni M, Jakse N. All-ceramic restoration of zirconia two-piece implants - a randomized controlled clinical trial. Clin Oral Implants Res. 2015;26:371–6. https://doi.org/10.1111/clr.12342, PMID:24502675

[51] Zembic A, Bösch A, Jung RE, Hämmerle CHF, Sailer I. Five-year results of a randomized controlled clinical trial comparing zirconia and titanium abutments supporting single-implant crowns in canine and posterior regions. Clin Oral Implants Res. 2013;24:384–90. https://doi.org/10.1111/clr.12044, PMID:23025514

[52] Zembic A, Sailer I, Jung RE, Hämmerle CHF. Randomized-controlled clinical trial of customized zirconia and titanium implant abutments for single-tooth implants in canine and posterior regions: 3-year results. Clin Oral Implants Res. 2009;20:802–8. https://doi.org/10.1111/j.1600-0501.2009.01717.x, PMID:19486077

[53] Hu M, Chen J, Pei X, Han J, Wang J. Network meta-analysis of survival rate and complications in implant-supported single crowns with different abutment materials. J Dent. 2019;88:103115. https://doi.org/10.1016/j.jdent.2019.04.007, PMID:30986515

[54] Sanz-Sánchez I, Sanz-Martín I, Carrillo de Albornoz A, Figuero E, Sanz M. Biological effect of the abutment material on the stability of peri-implant marginal bone levels: A systematic review and meta-analysis. Clin Oral Implants Res. 2018;29(suppl 18):124–44. https://doi.org/10.1111/clr.13293, PMID:29907973

[55] Bergemann C, Duske K, Nebe JB, Schöne A, Bulnheim U, Seitz H, *et al.* Microstructured zirconia surfaces modulate osteogenic marker genes in human primary osteoblasts. J Mater Sci Mater Med. 2015;26:26. https://doi.org/10.1007/s10856-014-5350-x, PMID:25578704

[56] Markarian R, Vasconcelos E, Kim J, Attard N, Cortes A. Effect of Different Milling Devices on Marginal Fit of CAD/CAM Zirconia Copings on Implant Stock Abutments. Int J Prosthodont. 2022;35:420–4. https://doi.org/10.11607/ijp.7069, PMID:33625396

[57] Paul N, Raghavendra Swamy KN, Dhakshaini MR, Sowmya S, Meravini M. Marginal and internal fit evaluation of conventional metal-ceramic versus zirconia CAD/CAM crowns. J Clin Exp Dent. 2020;12:e31–7. https://doi.org/10.4317/medoral.55946, PMID:31976041

[58] Pandoleon P, Bakopoulou A, Papadopoulou L, Koidis P. Evaluation of the biological behaviour of various dental implant abutment materials on attachment and viability of human gingival fibroblasts. Dent Mater. 2019;35:1053–63. https://doi.org/10.1016/j.dental.2019.04.010, PMID:31060818

[59] Welander M, Abrahamsson I, Berglundh T. The mucosal barrier at implant abutments of different materials. Clin Oral Implants Res. 2008;19:635–41. PMID:18492075

[60] Sculean A, Gruber R, Bosshardt DD. Soft tissue wound healing around teeth and dental implants. J Clin Periodontol. 2014;41(suppl 15):S6–22. https://doi.org/10.1111/jcpe.12206, PMID:24641001

[61] Khzam N, Arora H, Kim P, Fisher A, Mattheos N, Ivanovski S. Systematic Review of Soft Tissue Alterations and Esthetic Outcomes Following Immediate Implant Placement and Restoration of Single Implants in the Anterior Maxilla. J Periodontol. 2015;86:1321–30. https://doi.org/10.1902/jop.2015.150287, PMID:26313019

[62] Canullo L, Pesce P, Patini R, Antonacci D, Tommasato G. What Are the Effects of Different Abutment Morphologies on Peri-implant Hard and Soft Tissue Behavior? A Systematic Review and Meta-Analysis. Int J Prosthodont. 2020;33:297–306. https://doi.org/10.11607/ijp.6577, PMID:32320183

[63] Canullo L, Genova T, Gross Trujillo E, Pradies G, Petrillo S, Muzzi M, *et al.* Fibroblast Interaction with Different Abutment Surfaces: In Vitro Study. Int J Mol Sci. 2020;21:1919. https://doi.org/10.3390/ijms21061919, PMID:32168919

[64] Canullo L, Tallarico M, Peñarrocha-Oltra D, Monje A, Wang HL, Peñarrocha-Diago M. Implant Abutment Cleaning by Plasma of Argon: 5-Year Follow-Up of a Randomized Controlled Trial. J Periodontol. 2016;87:434–42. https://doi.org/10.1902/jop.2015.150549, PMID:26561996

[65] Mbuagbaw L, Rochwerg B, Jaeschke R, Heels-Andsell D, Alhazzani W, Thabane L, *et al.* Approaches to interpreting and choosing the best treatments in network meta-analyses. Syst Rev. 2017;6:79. https://doi.org/10.1186/s13643-017-0473-z, PMID:28403893