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REVIEW ARTICLE

WILEY CLINICAL ORAL IMPLANTS RESEARCH

Biological effect of the abutment material on the stability of peri-implant marginal bone levels: A systematic review and meta-analysis

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Abstract

Objectives: The primary aim of this systematic review was to evaluate the available evidence on the effect of the abutment material on the stability and health of the peri-implant hard tissues.

Methods: A protocol was developed to answer the following focused question: "Which is the effect of the abutment material on stability and health of the peri-implant hard tissues?" Randomized controlled trials (RCTs), controlled clinical trials (CCTs) or prospective case series (CS) with at least 6 months of follow-up were included, and meta-analyses were performed to compare abutment materials vs. titanium and to evaluate the impact of various abutment materials on bone changes (primary outcome), probing depth, plaque levels and peri-implant mucosal inflammation.

Results: Twenty-nine publications from 33 investigations were included. Results from the meta-analyses demonstrated no significant differences between the different abutment materials when compared to titanium, in regard to the changes in marginal bone levels (MBLs) (n = 15; WMD = 0.034; 95% CI [−0.04, 0.10]; p < 0.339). The meta-analysis reported a significantly greater increase in bleeding on probing for titanium compared to zirconia abutments (n = 3; WMD = −26.96%; 95% CI [−45.00%, −8.92%]; p = 0.003). When evaluating the behaviour of each material different to titanium, there was a significant bone loss over time (n = 31; WMD = 0.261; 95% CI [0.18, 0.35]; p < 0.001) for all the individual materials except for titanium nitride.

Conclusions: This systematic review has shown that the abutment material had minimal impact on marginal bone levels when compared to the standard titanium.

KEYWORDS
dental abutment, dental implants, dental-implant abutment material, periodontal index, radiograph, systematic review

1 | INTRODUCTION

Osseointegrated implants have been well described in regard to their healing outcomes (Albrektsson, Branemark, Hansson, & Lindstrom, 1981; Davies, 1998) as well as their clinical outcomes, demonstrating a clear benefit for the patient's masticatory efficiency and quality of life (Angkaew, Serichetaphongse, Krisdapong, Dart, & Pimkhaokham, 2017; Kutkut et al., 2017). Even though changes in surface morphology have shortened treatment times and allowed for earlier delivery of functional restorations (Wennerberg & Albrektsson, 2009, 2010), there is still controversy concerning the soft tissue integration that occurs at the transmucosal zone and the impact that the abutment composition and surface texture may have on the stability and health of the peri-implant tissues (Tomasi et al., 2014).

Preclinical investigations have shown the lack of direct attachment between the implant abutment and the supracrestal connective tissues (Abrahamsson, Berglundh, Wennstrom, & Lindhe, 1996; Berglundh & Lindhe, 1996), which may impact the soft tissue sealing and the protection of the peri-implant hard tissue from the highly contaminated environment in the oral cavity (Salvi et al., 2015). When selecting materials for abutments, clear prerequisites are a proven biological compatibility for assuring long-term stability together with optimal biomechanical and physical properties. Preclinical in vivo research has shown that abutment material composition may indeed affect the peri-implant mucosa and its location, which secondarily influences the marginal bone levels (Abrahamsson, Berglundh, Glantz, & Lindhe, 1998; Welander, Abrahamsson, & Berglundh, 2008).

Titanium has been the material of choice for abutments due to its biocompatibility and long-term predictability demonstrated in many clinical studies (Andersson, Bergenblock, Furst, & Jemt, 2013; Bergenblock, Andersson, Furst, & Jemt, 2012). However, as with all metal abutments, titanium abutments risk the effect of a grey discoloration of the peri-implant soft tissue, which represents a clear drawback when aesthetics is of importance (Ioannidis et al., 2017; Jung et al., 2008).

With the advent of new biomaterials, such as coloured zirconia (Buchi, Sailer, Fehmer, Hammerle, & Thoma, 2014), and high-strength ceramics (Kohal, Att, Bachle, & Butz, 2008), such as lithium disilicate (Mehl et al., 2016), titanium-free abutments are becoming routinely used in clinical practice, as they have shown improved optical properties (Park, Da Silva, Weber, & Ishikawa-Nagai, 2007), less plaque accumulation and inflammation (Nakamura, Kanno, Milleding, & Ortengren, 2010; Sanz-Martín, Sanz-Sanchez, Carrillo de Albornoz, Figuero, & Sanz, 2017) and a reliable clinical behaviour with limited technical complications (Ekfeldt, Furst, & Carlsson, 2017; Zembic, Philipp, Hammerle, Wohlwend, & Sailer, 2015). In spite of these innovations, there is a lack of evidence on their long-term effect on the hard and soft peri-implant tissues. As tissue healing outcomes can only be evaluated through histology, surrogate outcomes have been used in clinical studies to evaluate the possible impact of abutment materials, namely, the changes in marginal bone levels and the changes in the stability of the peri-implant mucosa by evaluating probing depths and clinical inflammation.

Therefore, the primary aim of this review was to evaluate the available evidence on the effect of the abutment material on the stability and health of the peri-implant hard tissues. The secondary objective was to further evaluate the available evidence on the impact of the abutment materials on other clinical parameters such as mucosal inflammation, probing depth or peri-implant soft tissue levels.

2 | MATERIAL AND METHODS

2.1 | Protocol development and eligibility criteria

A protocol was developed a priori, with the aim to answer the following focused question: *Which is the effect of the abutment material on the stability and health of the peri-implant tissues?* This protocol fulfilled the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) recommendations (Moher, Liberati, Tetzlaff, & Altman, 2009).

2.1.1 | Inclusion criteria (PICOS)

- Population: systemically healthy patients requiring at least one abutment connected to an implant.
- Intervention: any abutment material (titanium, zirconia, gold, alumina, etc.).
- Comparison: any abutment material (titanium, zirconia, gold, alumina, etc.) with or without the same macroscopic design than the intervention group or the absence of treatment.
- Outcomes: The primary outcome was the changes in radiographic marginal bone levels (MBLs)
- Study design: randomized controlled trials (RCTs), controlled clinical trials (CCTs) or prospective case series (CS) with at least 6 months of follow-up after abutment connection and with a minimum of 10 patients (5 per group in controlled studies).

2.1.2 | Exclusion criteria

- Any study comparing the effect of different implant–abutment connections (e.g., switching platform), different implant macrodesigns, different surgical approaches or different loading protocols;
- Studies investigating mini-implants and/or orthodontic anchorage devices;
- Studies evaluating the behaviour of abutments used to retain removable prosthesis;
- Studies evaluating different abutments in preclinical investigations.

2.1.3 | Type of intervention and comparisons

Studies were selected when they were designed to compare the clinical behaviour of different implant abutment materials (RCTs and CCTs) or when evaluating alternative materials to titanium (CS).

2.1.4 | Types of outcomes

The primary outcome of this systematic review was the change in radiographic MBLs. This level is defined as the distance between the implant shoulder and the first bone to implant contact measured at both mesial and distal aspects. In the studies where the mesial and distal values were reported independently, their means were combined (Higgins & Green 2011).

As secondary outcomes, the following were evaluated: implant survival, implant success, probing depth (PD), gingival or bleeding index, plaque index (PI), peri-implant soft tissue levels (changes in the level of the buccal peri-implant mucosal margin, tissue thickness and in papilla height), dimension of keratinized mucosa, colour of the mucosa, any aesthetic index, the rate and type of technical complications, patient-reported outcome measures (PROMs) and the occurrence of biological complications. Biological complications were defined as the occurrence of peri-implant mucositis (bleeding on probing (BOP) with or without increased PD and without radiographic bone loss) and/or peri-implantitis (BOP with or without increased PD and with radiographic bone loss; Lang & Berglundh, 2011).

2.2 | Information sources and search

2.2.1 | Electronic search

Two electronic databases were used as sources in the search for studies satisfying the inclusion criteria: (a) the National Library of Medicine (MEDLINE via PubMed) and (b) Cochrane Central Register of Controlled Trials. These databases were searched for studies published until September 2017. The search was limited to human subjects and to English language.

The following search terms were used:

Population

[MeSH terms]: Dental implants OR Dental Implants, Single-Tooth OR Dental Implantation OR Dental Prosthesis, Implant-Supported OR Dental Implantation, Endosseous

OR

[Text Words]: “Dental implants” OR “Dental implant” OR ((Implant OR Implants) AND Dental)

Intervention

[MeSH terms]: Dental abutments OR dental implant abutment design

OR

[Text Word]: abutment OR abutments OR “prosthetic abutment” OR “implant abutment” OR “implant abutments”

Outcome

[MeSH terms]: alveolar bone loss OR bone resorption

OR

[Text Word]: “bone loss” OR “marginal bone loss” OR “radiographic bone loss” OR “radiographic marginal bone loss” OR “interproximal bone loss” OR “radiographic interproximal bone loss” OR “bone level” OR “bone levels” OR “marginal bone level” OR “marginal bone levels” OR “interproximal bone level” OR “interproximal bone levels” OR “radiographic bone level” OR “radiographic bone levels” OR “radiographic interproximal bone level” OR “radiographic interproximal bone levels” OR “radiographic marginal bone level” OR “radiographic marginal bone levels” OR x-ray OR radiograph

Population AND Intervention AND outcome

All reference lists of the selected studies were checked for cross-references. The following journals were hand-searched from 2007 to 2017: *Journal of Clinical Periodontology*, *Journal of Periodontology*, *Clinical Oral Implants Research*, *International Journal of Oral & Maxillofacial Implants*, *European Journal of Oral Implantology*, *Implant Dentistry*, *International Journal of Periodontics and Restorative Dentistry*, *International Journal of Prosthodontics*, *Journal of Prosthetic Dentistry* and *Clinical Implant Dentistry and Related Research*.

2.2.2 | Screening methods

Two reviewers (ISS and AC) did the primary search by screening independently the titles and abstracts. The same reviewers selected for evaluation the full manuscript of those 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 (ISM). To calibrate the inter-reviewer reliability, percentages of agreement and kappa coefficients were calculated.

2.2.3 | Data extraction

Two reviewers (ISS and ISM) extracted the data. Authors of studies were contacted for clarification when data were incomplete or missing. Data were excluded until further clarification could be available if agreement could not be reached. When the results of a study were published more than once, the data with longest follow-up were included only once.

2.2.4 | Quality assessment (risk of bias in individual studies)

A quality assessment of the included RCTs and CCTs was performed following the Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 (updated March 2011; Higgins & Green, 2011). Six main quality criteria were assessed: sequence generation, allocation concealment, blinding treatment outcomes to outcome examiners, completeness of follow-up, selective outcome reporting and other sources of bias. These criteria were rated as low, unclear or high risk of bias depending on the descriptions given for each individual field.

A modification of the Newcastle–Ottawa Scale for observational studies was used for evaluating the risk of bias of the observational studies (Wells et al. 2011). This scale includes four main categories: representativeness of the exposed cohort, ascertainment of exposure, assessment of outcome and follow-up long enough for the outcome of interest.

2.2.5 | Risk of bias across studies

The publication bias was evaluated using Funnel plots and the Egger's linear regression method for MBL changes. A sensitivity analysis of the meta-analysis results was also performed for this outcome (Tobias & Campbell, 1999).

2.2.6 | Data analyses

The statistical heterogeneity among studies was assessed using the Q test based on chi-square statistics (Cochrane, 1954) as well as the I^2 index (Higgins, Thompson, Deeks, & Altman, 2003) to know the percentage of variation in the global estimate that was attributable to heterogeneity (I^2 = 25%: low; I^2 = 50%: moderate; I^2 = 75%: high heterogeneity).

To summarize and compare studies, mean values of primary (MBL changes) and quantitative secondary outcomes (PD, PI, BOP changes) were directly pooled and analysed with weighted mean differences (WMDs) and 95% confidence intervals (CIs). In the case of the dichotomous outcome, such as technical complications, the estimates of the effect were expressed in risk ratios (RR) and 95% CIs. Study-specific estimates were pooled with both the fixed and random- effect models (DerSimonian & Laird, 1986), and the random-effect model results were presented. Two groups of meta-analyses were performed based on the study design: (a) When comparing specific abutment material vs. titanium, only RCTs or CCTs were included. In the case of studies with more than two arms, each intervention was compared against the control group (titanium). (b) When comparing mean changes of the studied outcomes between final and baseline visits, CS and each test arm of RCTs and the CCTs were included (Sanz-Sanchez, Ortiz-Vigon, Sanz-Martín, Figuero, & Sanz, 2015). In addition, subgroup analyses were performed on the selected outcome variables using the type of test abutment material (zirconia, gold, alumina, etc.) as explanatory variable. For the main outcome, subgroup analyses were performed using the type of study design (CS, CCTs, RCTs [split+parallel], RCTs [split] or RCTs [parallel]) or the unit of analysis (patient or implant) as explanatory variable. Forest plots were created to illustrate the effects of the meta-analysis and the global estimations. STATA-14® (StataCorp LP, Lakeway Drive, College Station, TX, USA) intercooled software was used to perform all analyses. Statistical significance was defined as a p-value <0.05.

3 | RESULTS

3.1 | Search

Figure 1 depicts the flow chart summarizing the results of the selection. The electronic search rendered 1,705 titles, which after evaluating their titles and abstracts (agreement = 92.14%; kappa = 0.37; 95% CI [0.29–0.45]; p < 0.001) resulted in selecting 78 studies and rejecting 1,627 studies. Seven further articles were identified through manual search, which resulted in a selection of 85 studies for full-text analysis (agreement = 96.10%; kappa = 0.92; 95% CI [0.83–1.00]; p < 0.001). After this analysis, 33 final articles were included for data extraction, which represented 29 independent investigations, as in four groups articles, results of the same material were reported at different time points (Andersson, Glauser, Maglione, & Taylor, 2003; Andersson, Scharer, Simion, & Bergstrom, 1999; Brown & Payne, 2011; Nothdurft, Nonhoff, & Pospiech, 2014; Nothdurft & Pospiech, 2010; Tawse-Smith et al., 2017; Zembic, Bosch, Jung, Hammerle, & Sailer, 2013; Zembic, Sailer, Jung, & Hammerle, 2009). The reasons for exclusion of the remaining studies are detailed in Supporting Information Table S1.

3.2 | Description of selected studies

Their methodological characteristics are reported in Table 1. From the 29 investigations, 9 were case series, 5 CCTs and 15 RCTs (11 had a parallel design, 2 a split-mouth design and 2 combined a parallel and a split-mouth design). Among the controlled studies, two had more than one experimental group meeting the inclusion criteria, so data from each experimental group were analysed independently (Ferrari, Cagidiaco, Garcia-Godoy, Goracci, & Cairo, 2015; Hosseini, Worsaae, Schiodt, & Gotfredsen, 2013). All controlled studies, except for six, used titanium as the control abutment, and only these studies were included in the meta-analysis. In the six remaining studies, one used gold (Gallucci, Grutter, Chuang, & Belser, 2011), one zirconia (Thoma et al., 2016) and one alumina (Chen, Nang, Wang, & Luo, 2008) as control abutments, two compared different fabrication methods of ceramic abutments (Schepke, Meijer, Kerdijk, Raghoebar, & Cune, 2017; Wittneben et al., 2017), and one compared two different impression protocols for ceramic abutments (Erhan Comlekoglu, Nizam, & Comlekoglu, 2018). In these six studies, each arm was considered independent and evaluated together with the selected case series when evaluating the behaviour of the abutment material different from titanium. Among the selected CS, five evaluated zirconia, two alumina, one titanium nitride and one a compound material made of zirconia and alumina, as abutment materials.

The resulting systematic review pooled data of 1,026 patients at baseline, baring a total of 1,354 implants. The mean follow-up period was 30.05 months, with a minimum of 6 months in one study (Oh, Shotwell, Billy, & Wang, 2006; Tozum, Turkyilmaz, Yamalik, Karabulut, & Eratalay, 2007) and a maximum of 86.4 months in another (Turkyilmaz, Tozum, Fuhrmann, & Tumer, 2012). At the end of the study, 954 patients bearing a total of 1,266 remaining implants were followed.

3.3 | Risk of bias in individual studies

Table 2 depicts the risk-of-bias scores for the included RCTs and CCTs, depicting each criterion individually. No single study demonstrated low risk of bias for all the criteria. Five studies, however, had a low risk of bias for five criteria (Carrillo de Albornoz et al., 2014; Gallucci et al., 2011; Hosseini, Worsaae, Schiodt, & Gotfredsen,

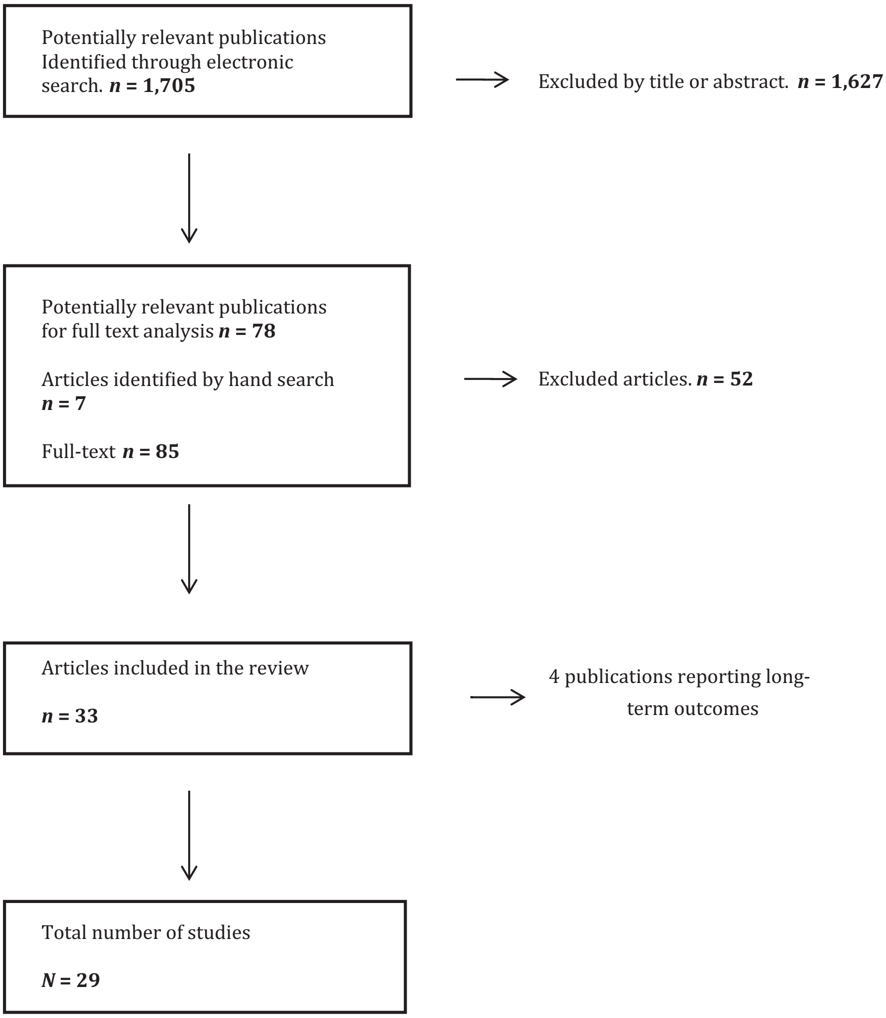

FIGURE 1 Flow chart depicting the article selection process

2011; Schepke et al., 2017; Wittneben et al., 2017). The remaining studies had a high or unclear risk of bias in two or more criteria.

The quality of reporting in the selected case series studies is depicted in Table 3. Only one study (Nothdurft et al., 2014) met the four quality categories.

3.4 | Risk of bias across studies

No significant publication bias was observed when combining all controlled studies for the main outcome measure ($p = 0.692$). However, a statistically significant publication bias was observed for the same outcome when combining all studies ($p < 0.001$). The sensitivity analyses showed that the exclusion of a single study did not substantially alter any estimate.

3.5 | Effects of Interventions

3.5.1 | Main outcome: marginal bone level changes

Table 4 depicts the meta-analysis for differences in bone loss when comparing different abutment materials to titanium in controlled studies. One controlled study (Fenner, Hammerle, Sailer, & Jung, 2016) could not be included in the meta-analysis as only final mean values were provided. No significant WMDs were encountered when comparing the different test materials with titanium ($n = 15$; WMD = 0.034; 95% CI [−0.04, 0.10]; $p = 0.339$). Similarly, no significant differences were observed for any of the individual comparisons (alumina, gold, titanium nitride or zirconia). Figure 2 depicts the magnitude of these differences when compared to titanium, showing the wider difference for alumina and the smaller for gold.

Within each group, the behaviour of the different abutment materials revealed a significant bone loss over time, both for the overall evaluation ($n = 31$; WMD = 0.261; 95% CI [0.18, 0.35]; $p < 0.001$) and for all the individual materials, except for titanium nitride, although the mean bone loss reported was never clinically significant (Table 5, Figure 3). Alumina demonstrated the greatest bone level change and lithium disilicate the smallest. Studies reporting only final values or mean values without standard deviations could not be included in the meta-analysis (Chen et al., 2008; Fenner et al., 2016; Wittneben et al., 2017). When evaluating the results depending on the study design, case series demonstrated greater bone level changes than the three different types of RCTs, whereas no differences were seen depending on the unit of analysis (patient or implant).

TABLE 1 Methodological characteristics of the studies included

Reference	Type of study	Follow-up	Test patients' baseline (final)/control patients' baseline (final)	Test implants/ control implants	Type of restoration	Interventions control	Interventions test
RCTs							
Andersson et al. (1999)	RCT Parallel	24	16 (16)/16 (16)	50/53	FPDs	Titanium	Alumina
Andersson et al. (2003)	RCT Parallel	60	16 (14)/16 (15)	50/47	FPDs	Titanium	Alumina
Andersson et al. (2001)	RCT Parallel	12	NR	34/35	Single tooth	Titanium	Alumina
Baldini et al. (2016)	RCT Parallel	12	12 (10)/12 (12)	10/12	Single tooth	Titanium	Zirconia
Carrillo de Albornoz et al. (2014)	RCT Parallel	12	12 (11)/14 (14)	14/11	Single tooth	Titanium	Zirconia
Chen et al. (2008)	RCT Parallel	21	Total 23	18/17	Single tooth	Alumina	Zirconia
Erhan Comlekoglu et al. (2018)	RCT Split	24	16 (16)/16 (16)	16/16	Single tooth	Li-DIS conv	Li-DIS def
Fenner et al. (2016)	RCT Parallel	86.4	15 (13)/15 (15)	20/16	Single tooth	Titanium	Alumina
Ferrari et al. (2015)	RCT Parallel	24	18 (18)/15 (15)/14 (14)	27/44/28	Single tooth	Titanium	TiNi/zirconia
Gallucci et al. (2011)	RCT Parallel	24	10 (8)/10 (9)	10/10	Single tooth	Gold	Alumina
Hosseini et al. (2011)	RCT Par/Split	12	30 (30)/29 (29)	37/38	Single tooth	Titanium	Zirconia
Schepke et al. (2017)	RCT Parallel	12	25 (25)/25 (25)	25/25	Single tooth	Zirconia stock	Zirconia CAD
Thoma et al. (2016)	RCT Parallel	15	10 (10)/10 (10)	10/10	Single tooth	Zirconia	Zirconia+ceramic
Vigolo et al. (2006)	RCT Split	48	20 (20)/20 (20)	20/20	Single tooth	Titanium	Gold
Wittneben et al. (2017)	RCT Parallel	12	20 (20)/20 (18)	20/20	Single tooth	Zirconia stock	Zirconia CAD
Zembic et al. (2009)	RCT Par/Split	36	NR	10/18	Single tooth	Titanium	Zirconia
Zembic et al. (2013)	RCT Par/Split	67	NR	10/18	Single tooth	Titanium	Zirconia
Hosseini et al. (2013)	CCT	36	30 (NR)/29 (NR)	21/15/52	Single tooth	Titanium	Gold/Zirconia
Lops, Bressan, Chiapasco, Rossi, and Romeo (2013)	CCT	60	38 (37)/47 (44)	37/44	Single tooth	Titanium	Zirconia
Lops et al. (2016)	CCT	24	14 (14)/19 (19)	14/19	Single tooth	Titanium	Zirconia
Wannfors and Smedberg (1999)	CCT	36	42 (NR)/34 (NR)	42/34	Single tooth	Titanium	Gold
Vanlioglu, Ozkan, Evren, and Ozkan (2012)	CCT	60	6 (6)/6 (6)	6/6	Single tooth	Titanium	Zirconia
Bae et al. (2008)	Case Series	12	19 (19)	19	Single tooth		Alumina–zirconia
Brown and Payne (2011)	Case Series	12	25 (25)	25	Single tooth		Zirconia
Tawse-Smith et al. (2017)	Case Series	60	25 (16)	16	Single tooth		Zirconia
Calvo Girado, Saez Yuguero, Pardo Zamora, and Muñoz Barrio (2007)	Case Series	6	10 (10)	10	Single tooth		Titanium nitride
Cardaropoli et al. (2006)	Case Series	12	16 (11)	11	Single tooth		Alumina
Glauser et al. (2004)	Case Series	49	27 (18)	18	Single tooth		Zirconia

Continues

TABLE 1 Continued

Reference	Type of study	Follow-up	Test patients' baseline (final)/control patients' baseline (final)	Test implants/ control implants	Type of restoration	Interventions control	Interventions test
Henriksson and Jemt (2003)	Case Series	12	20 (19)	19	Single tooth		Alumina
Nilsson et al. (2017)	Case Series	54	52 (35)	35	Single tooth		Zirconia
Nothdurft and Pospiech (2010)	Case Series	12	24 (24)	24	Single tooth		Zirconia
Nothdurft et al. (2014)	Case Series	36	24 (23)	23	Single tooth		Zirconia
Santing, Raghoebar, Vissink, den Hartog, and Meijer (2013)	Case Series	18	60 (60)	60	Single tooth		Zirconia

Note. CAD: computer-assisted design; CCT: controlled clinical trial; FPDs: fixed partial dentures; Li-DIS conv: lithium disilicate made through conventional impressions after implant integration; Li-DIS def: lithium disilicate definitive abutment; NR: not reported; Par: parallel; RCT: randomized controlled trial.

3.5.2 | Secondary outcomes

Table 6 depicts which studies reported each of the secondary outcomes analysed in the systematic review.

Implant survival and success

Implant survival was reported in all the studies except one (Ferrari et al., 2015), with the aggregated mean implant survival rate being 99.2% (min: 89%; max: 100%). For the CS, this mean implant survival was 99.4%, whereas for controlled studies, no significant differences were met between the test and control groups (98.8% and 99.4%, respectively). Implant success using specific criteria was reported in five studies. Four studies used the Albrektsson and Zarb (1998) criteria, reporting an implant success rate of 100% (Brown & Payne, 2011; Glauser et al., 2004; Tawse-Smith et al., 2017; Vanlioglu et al., 2012). One study used the Buser, Weber, Bragger, and Balsiger (1991) criteria, reporting implant success rates of 94.7% and 100% in the test and control groups, respectively (Wittneben et al., 2017).

Probing depth

Probing depth was assessed in 15 of the 29 investigations. In five studies, only final values were reported or the results were pooled for both study groups, so these were not included in the meta-analysis (Fenner et al., 2016; Ferrari et al., 2015; Hosseini et al., 2011; Tawse-Smith et al., 2017; Vigolo, Givani, Majzoub, & Cordioli, 2006). Table 4 depicts the meta-analysis demonstrating similar PDs among the different abutment materials, without significant differences for the overall analysis or the individual comparisons. When evaluating the changes over time for abutment materials different to titanium, there was an overall significant increase in PD (n = 14; WMD = 0.57; 95% CI [0.20, 0.94]; p = 0.003), and when evaluated individually by abutment material, only zirconia demonstrated a significant increase in PD (n = 12; WMD = 0.35; 95% CI [0.09, 0.61]; p = 0.009) (Table 5).

Bleeding and gingival indices

Bleeding was registered in 21 of the 29 investigations, with the sulcus bleeding index (Mombelli & Lang, 1994) and the percentage of sites positive to BOP being the most frequently used indices. In addition, one study used the gingival bleeding index by Ainamo and Bay (1975) (Tawse-Smith et al., 2017), one the simplified bleeding index by Apse, Zarb, Schmitt, and Lewis (1991) (Glauser et al., 2004) and one the gingival index by Lang, Joss, Orsanic, Gusberti, and Siegrist (1986) (Wittneben et al., 2017). Seven studies could not be included in the meta-analysis, as either only final values were reported (Fenner et al., 2016; Nilsson, Johansson, Lindh, & Ekfeldt, 2017; Tawse-Smith et al., 2017; Vigolo et al., 2006), or data were expressed as medians (Hosseini et al., 2011), or the results were only reported in figures (Santing, Raghoebar, Vissink, den Hartog, & Meijer, 2013), or when no values were provided even though the authors reported their measurement (Vanlioglu et al., 2012). The meta-analysis reported a statistically significantly greater increase in BOP for titanium compared to

TABLE 2 Risk-of-bias assessment according to the Cochrane Collaboration recommendations (Higgins and Green, 2011)

References	Selection bias sequence generation	Selection bias allocation concealment	Performance bias	Detection bias	Attrition bias	Selective reporting bias	Other potential risk of bias
Vanlioglu et al. (2012)	High	High	High	High	Low	Unclear	High
Ferrari et al. (2015)	Low	Low	High	Low	High	Low	High
Andersson et al. (2003)	Low	High	High	High	Low	Low	Low
Andersson et al. (1999)	Low	High	High	High	Low	Low	High
Andersson et al. (2001)	Low	High	High	High	Low	High	High
Gallucci et al. (2011)	Low	Low	Low	Low	Low	Low	High
Hosseini et al. (2013)	High	High	High	Low	Low	Low	High
Thoma et al. (2016)	Unclear	Unclear	High	High	Low	Low	High
Vigolo et al. (2006)	Low	Unclear	High	High	Low	Low	High
Zembic et al. (2013)	Low	High	High	High	Low	Low	Low
Zembic et al. (2009)	Low	High	High	High	Low	High	Low
Lops et al. (2013)	Unclear	High	High	High	Low	Low	Low
Carrillo de Albornoz et al. (2014)	Low	Low	Low	Low	Low	Low	High
Baldini et al. (2016)	Low	Low	Low	Low	Unclear	Low	High
Fenner et al. (2016)	Unclear	High	High	High	Low	Low	Low
Nilsson et al. (2017)	High	High	High	High	Low	Low	High
Wannfors and Smedberg (1999)	High	High	High	High	Low	Low	High
Chen et al. (2008)	Unclear	High	High	High	Low	High	High
Lops et al. (2016)	High	High	High	High	Low	Low	High
Schepke et al. (2017)	Low	Low	Low	High	Low	Low	Low
Wittneben et al. (2017)	Low	Low	Low	Low	Low	Low	High
Erhan Comlekoglu et al. (2018)	Low	Unclear	Unclear	Low	Low	Low	Low
Hosseini et al. (2011)	Low	Low	High	Low	Low	Low	Low

TABLE 3 Quality of reporting case series. Adaptation of the Newcastle–Ottawa Scale

References	Selection bias representativeness of the exposed cohort	Selection bias ascertainment of exposure	Outcome assessment of outcome	Outcome was follow-up long enough for outcomes to occur
Brown and Payne (2011)		*	*	
Tawse-Smith et al. (2017)		*	*	*
Calvo Guirado et al. (2007)		*	*	
Cardaropoli et al. (2006)		*	*	
Santing et al. (2013)	*	*	*	
Bae et al. (2008)		*	*	
Glauser et al. (2004)		*	*	*
Henriksson and Jemt (2003)		*	*	
Nothdurft and Pospiech (2010)	*	*	*	
Nothdurft et al. (2014)	*	*	*	*

zirconia abutments (n = 3; WMD = −26.96%; 95% CI [−45.00%, −8.92%]; p = 0.003; Table 4). When comparing the changes over time within each material, the only significant increase in BOP values could be observed for gold abutments (n = 1; mean difference = 4.31%; 95% CI [1.26%, 7.36%]; p = 0.006). In Table 5, the values of the changes in inflammation when recorded with categorical indices are depicted. A significant increase in inflammation occurred during the follow-up (n = 8; WMD = 0.07; 95% CI [0.02, 0.11]; p = 0.002).

Plaque indices

Plaque accumulation was recorded in 18 of the 29 investigations. The most frequently used indices were the modified plaque index (Mombelli, van Oosten, Schurch, & Land, 1987) and the percentage of sites with visible plaque (PI%). In addition, one study used the plaque index by O'Leary, Drake, and Naylor (1972) (Tawse-Smith et al., 2017) and another the plaque index by Silness and Loe (1964) (Nilsson et al., 2017). Seven studies could not be included in the meta-analysis, as either only final values were reported (Fenner

TABLE 4 Meta-analysis for differences in clinical outcomes for comparative studies: test vs. control

		Weighted mean difference (WMD)				Heterogeneity	
			95% CI				
Outcome	n	DL	Lower	Upper	p-value	I^2 (%)	p-value
Bone loss (mm)							
All	15	0.034	−0.036	0.105	0.339	54.8	0.008
Alumina vs. titanium	2	0.157	−0.048	0.363	0.133	6.0	0.302
Gold vs. titanium	3	0.004	−0.300	0.307	0.980	65.4	0.056
Titanium nitride vs. titanium	1	0.060	−0.183	0.303	0.628		
Zirconia vs. titanium	9	0.018	−0.063	0.099	0.668	62.6	0.008
PD (mm)							
All	6	0.053	−0.132	0.238	0.573	5.0	0.384
Alumina vs. titanium	1	−0.290	−1.020	0.440	0.436		
Zirconia vs. titanium	5	0.074	−0.122	0.271	0.458	7.6	0.363
BOP (%)							
All	6	−9.351	−24.724	6.022	0.233	74.6	0.001
Alumina vs. titanium	3	7.121	−0.181	14.424	0.056	0.0	0.752
Zirconia vs. titanium	3	−26.961	−45.000	−8.922	0.003	33.8	0.221
Plaque (%)							
All	4	−6.699	−15.427	2.028	0.132	0.0	0.421
Alumina vs. titanium	3	−4.067	−13.619	5.485	0.404	0.0	0.591
Zirconia vs. titanium	1	−20.000	−41.472	1.472	0.068		

Note. CI: confidence interval; DL: Dersimonian & Laird method.

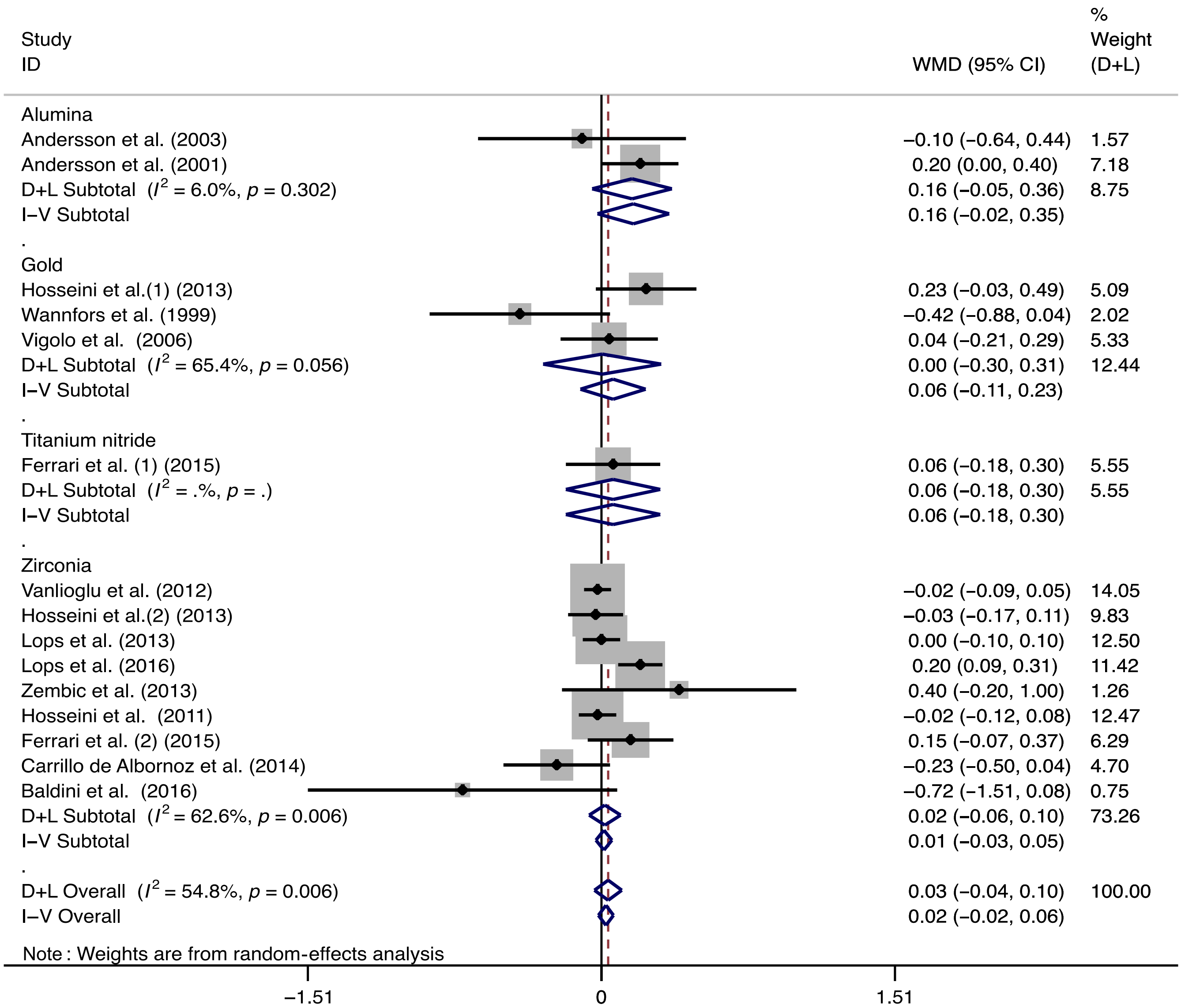

FIGURE 2 Forest plot for the changes in marginal bone levels for the different abutment materials compared to titanium

et al., 2016; Nilsson et al., 2017; Santing et al., 2013; Tawse-Smith et al., 2017; Vanlioglu et al., 2012; Vigolo et al., 2006) or data were expressed as medians (Hosseini et al., 2011, 2013). Even though no significant differences in the changes in plaque accumulation were found when comparing the different abutment materials, there was a trend for a greater plaque accumulation around titanium compared to zirconia abutments (n = 1; mean difference = −20.00%; 95% CI [−41.47%, 1.47%]; p = 0.068) (Table 4). Similarly, when evaluating the changes over time in the percentage of sites with visible plaque, there were no significant differences irrespective of the material used (Table 5). For categorical indices, there was a significant increase in plaque for zirconia abutments (n = 9; WMD = 0.25; 95% CI [0.07, 0.42]; p = 0.006).

Biological complications

In the evaluation of the onset of biological complications, the selected studies have used different case definitions, and due to this heterogeneity, no meta-analysis was attempted. The summary of the main findings is depicted in Table 7.

Peri-implant soft tissues

The evaluation of the peri-implant soft tissues (changes in the position of the mucosal margin, changes in the width of the keratinized mucosa, changes in the thickness of the mucosa or the height of the papilla) was scarcely carried out and was very heterogeneous, so no meta-analysis was performed. The recession of the mucosal margin was assessed in 10 investigations, reporting minimal or no changes over time, with a maximum recession of 0.6 (SD = 0.7; Cardaropoli, Lekholm, & Wennstrom, 2006), or even in some studies the occurrence of a coronal displacement of the buccal mucosal margin (Fenner et al., 2016). When comparing different abutment materials, minimal or no changes were observed in five studies (Andersson et al. 2001; Andersson et al., 2003; Carrillo de Albornoz et al., 2014; Schepke et al., 2017; Zembic et al., 2013), with only in one study, the titanium

TABLE 5 Meta-analysis for clinical outcomes in studies assessing a different material than titanium: final vs. baseline

		Weighted mean difference (WMD)				Heterogeneity	
			95% CI				
Index	*n*	DL	Lower	Upper	*p*-value	I^2 (%)	*p*-value
Bone levels (mesial & distal; mm)							
All	31	0.261	0.177	0.346	<0.001	93.7	<0.001
Study design							
Case series	8	0.455	0.216	0.694	<0.001	95.9	<0.001
CCTs	6	0.333	0.216	0.451	<0.001	91.1	<0.001
RCTs (split+parallel)	2	0.143	−0.081	0.366	0.211	42.0	0.189
RCTs (split)	3	0.172	0.000	0.345	0.050	91.4	<0.001
RCTs (parallel)	12	0.115	−0.056	0.287	0.188	90.6	<0.001
Unit of analyses							
Patient	20	0.259	0.129	0.390	<0.001	94.5	<0.001
Implant	11	0.259	0.148	0.369	<0.001	92.4	<0.001
Material							
Alumina	5	0.497	0.062	0.933	0.025	92.8	<0.001
Titanium nitride	2	0.270	−0.131	0.672	0.187	93.7	<0.001
Lithium disilicate	2	0.066	0.015	0.116	0.011	0.0	0.562
Zirconia	17	0.191	0.086	0.297	<0.001	94.1	<0.001
Zirconia+alumina	1	0.620	0.530	0.710	<0.001		
Gold	4	0.399	0.295	0.502	<0.001	0.0	0.730
PD (mm)							
All	14	0.570	0.196	0.945	0.003	97.6	<0.001
Alumina	2	1.887	−2.004	5.777	0.342	99.3	<0.001
Zirconia	12	0.351	0.088	0.613	0.009	94.8	<0.001
Plaque (%)							
All	8	2.683	−3.096	8.462	0.363	63.4	0.008
Alumina	4	7.695	−2.588	17.977	1.000	80.4	0.002
Zirconia	1	0.000	−13.859	13.859	0.092		
Gold	1	−3.940	−8.526	0.646	0.302		
Lithium disilicate	2	−16.500	−47.864	14.864	0.363	0.0	1.000
Plaque_other (MPI; Silness, O'Leary)							
All							
Zirconia	9	0.247	0.069	0.424	0.006	95.6	<0.001
BOP (%)							
All	11	2.818	−0.209	5.844	0.068	46.8	0.043
Zirconia	4	0.472	−8.889	9.832	0.921	61.7	0.050
Alumina	4	1.377	−2.778	5.532	0.516	33.3	0.213
Gold	1	4.310	1.259	7.361	0.006		
Lithium disilicate	2	10.344	−20.212	40.901	0.507	0.0	0.955
GI (SBI, Lang 86, SGI)							
All	8	0.070	0.025	0.115	0.002	0.0	0.833
Alumina	1	0.090	−0.081	0.261	0.303		
Zirconia	7	0.068	0.022	0.115	0.004	0.0	0.749

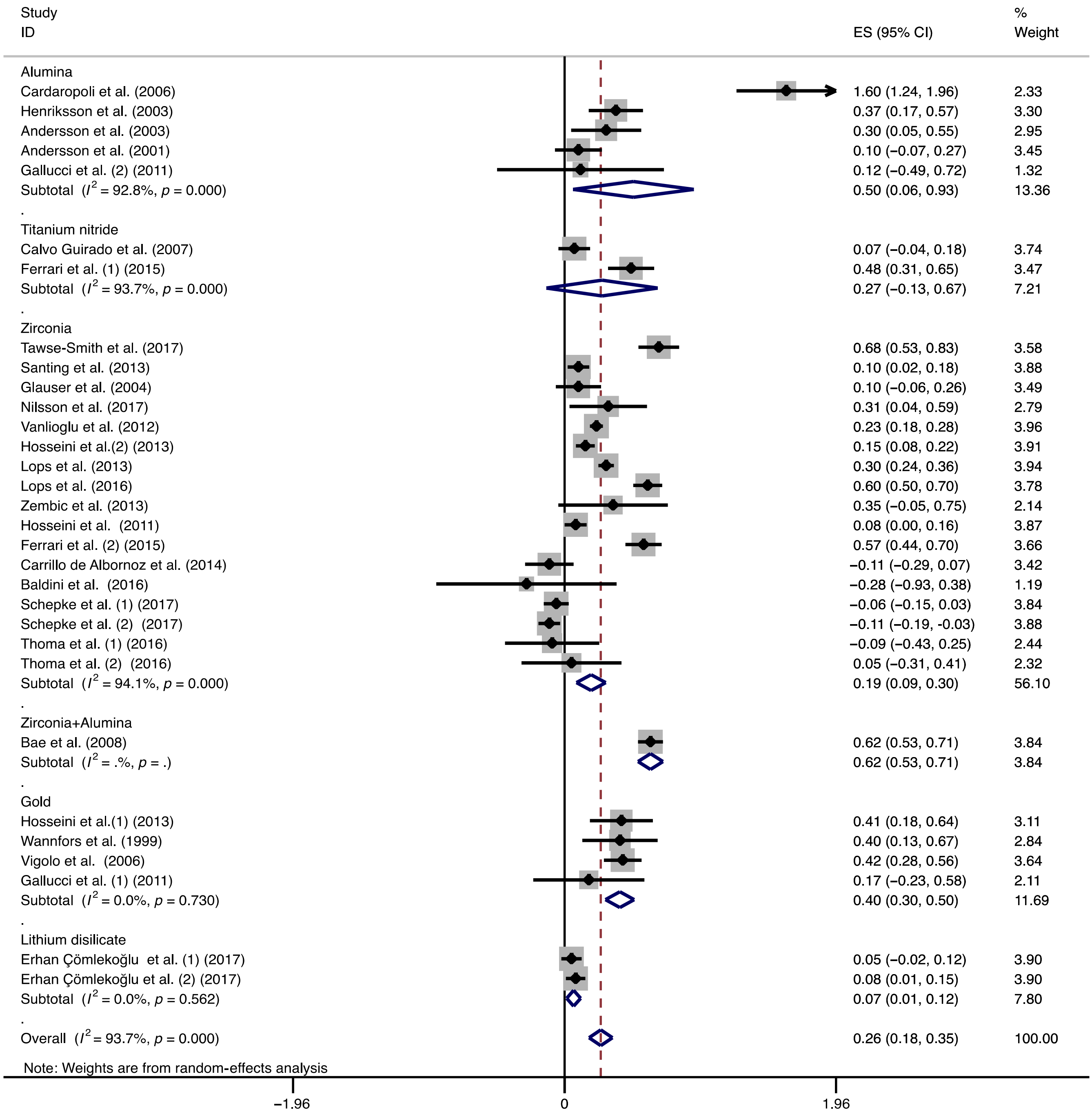

FIGURE 3 Forest plot for the changes in marginal bone levels within each type of abutment material different to titanium

abutment leading to greater recession (0.29 mm), when compared to alumina abutments (−0.31 mm; Fenner et al., 2016). The change in the position of the mucosal margin was also evaluated by assessing the length of the implant-supported crown (CLI) in four studies, demonstrating minimal or no change (0–0.86 mm; Carrillo de Albornoz et al., 2014; Fenner et al., 2016; Ferrari et al., 2015; Wittneben et al., 2017). In one study, this evaluation was carried out through clinical photographs with similar outcomes (Lops et al., 2016).

The width of the keratinized mucosa was recorded in eight studies, either as the mean values in mm (Cardaropoli et al., 2006; Carrillo de Albornoz et al., 2014; Fenner et al., 2016; Ferrari et al., 2015; Gallucci et al., 2011; Wittneben et al., 2017) or as the proportion of sites with a keratinized mucosa >2 mm (Tawse-Smith et al., 2017; Vigolo et al., 2006). The changes over time were minimal within groups (0–0.8 mm), and no differences were observed between the test and control groups. At the end of the study periods, the mean values varied between 3.04 mm (SD = 1.15) and 5.4 mm (SD = 1.7). The thickness of the mucosa was evaluated in six studies employing different techniques. One study used an ultrasound device and showed an increase in the thickness of 0.9 mm from implant placement to 1 year (Cardaropoli et al., 2006). Two other studies assessed the thickness above the bone crest before to implant placement using a calliper (Ferrari et al.,

TABLE 6 Secondary outcome assessment in the investigations included in the systematic review

Study outcome measured	References
Implant success	Brown and Payne (2011); Glauser et al. (2004); Tawse-Smith et al. (2017); Vanlioglu et al. (2012); Wittneben et al. (2017)
Probing depth	Tawse-Smith et al. (2017); Cardaropoli et al. (2006); Santing et al. (2013); Nothdurft et al. (2014); Vanlioglu et al. (2012); Ferrari et al. (2015); Vigolo et al. (2006); Zembic et al. (2013); Lops et al. (2013); Carrillo de Albornoz et al. (2014); Baldini et al. (2016); Fenner et al. (2016); Schepke et al. (2017); Wittneben et al. (2017); Hosseini et al. (2011)
Bleeding or gingival indices	Tawse-Smith et al. (2017); Cardaropoli et al. (2006); Santing et al. (2013); Glauser et al. (2004); Nothdurft et al. (2014); Vanlioglu et al. (2012); Andersson et al. (2003); Gallucci et al. (2011); Hosseini et al. (2013); Vigolo et al. (2006); Zembic et al. (2013); Lops et al. (2013); Carrillo de Albornoz et al. (2014); Baldini et al. (2016); Fenner et al. (2016); Nilsson et al. (2017); Schepke et al. (2017); Wittneben et al. (2017); Erhan Comlekoglu et al. (2018)
Plaque indices	Tawse-Smith et al. (2017); Santing et al. (2013); Glauser et al. (2004); Nothdurft et al. (2014); Vanlioglu et al. (2012); Andersson et al. (2003); Gallucci et al. (2011); Hosseini et al. (2013); Vigolo et al. (2006); Zembic et al. (2013); Lops et al. (2013); Fenner et al. (2016); Nilsson et al. (2017); Schepke et al. (2017); Wittneben et al. (2017); Erhan Comlekoglu et al. (2018)
Biological complications	Tawse-Smith et al. (2017); Cardaropoli et al. (2006); Santing et al. (2013); Bae et al. (2008); Henriksson and Jemt (2003); Nothdurft and Pospiech (2010); Vanlioglu et al. (2012); Hosseini et al. (2013); Thoma et al. (2016); Zembic et al. (2013); Lops et al. (2013); Carrillo de Albornoz et al. (2014); Nilsson et al. (2017); Wannfors and Smedberg (1999); Schepke et al. (2017)
Technical complications	Santing et al. (2013); Bae et al. (2008); Glauser et al. (2004); Nothdurft et al. (2014); Henriksson and Jemt (2003); Vanlioglu et al. (2012); Andersson et al. (1999, 2003); Andersson et al. (2001); Hosseini et al. (2013); Thoma et al. (2016); Vigolo et al. (2006); Zembic et al. (2013); Lops et al. (2013); Lops et al. (2016); Carrillo de Albornoz et al. (2014); Baldini (2016); Fenner et al. (2016); Nilsson et al. (2017); Wannfors and Smedberg (1999); Chen et al. (2008); Schepke et al. (2017); Wittneben et al. (2017); Erhan Comlekoglu et al. (2018)
Buccal mucosal margin	Cardaropoli et al. (2006); Ferrari et al. (2015); Andersson et al. (2001); Andersson et al. (2003); Zembic et al. (2013); Lops et al. (2016); Carrillo de Albornoz et al. (2014); Fenner et al. (2016); Schepke et al. (2017); Wittneben et al. (2017)
Width of keratinized mucosa	Tawse-Smith et al. (2017); Cardaropoli et al. (2006); Ferrari et al. (2015); Vigolo et al. (2006); Gallucci et al. (2011); Carrillo de Albornoz et al. (2014); Fenner et al. (2016); Wittneben et al. (2017)
Thickness of mucosa	Cardaropoli et al. (2006); Ferrari et al. (2015); Zembic et al. (2009); Carrillo de Albornoz et al. (2014); Baldini et al. (2016); Lops et al. (2016)
Height of interproximal papilla	Brown and Payne (2011); Cardaropoli et al. (2006); Santing et al. (2013); Henriksson and Jemt (2003); Zembic et al. (2013); Gallucci et al. (2011); Carrillo de Albornoz et al. (2014); Baldini et al. (2016); Fenner et al. (2016); Thoma et al. (2016)
Colour (spectrophotometer)	Zembic et al. (2009)
Aesthetic indices	Santing et al. (2013); Andersson et al. (2001); Andersson et al. (2003); Carrillo de Albornoz et al. (2014); Baldini et al. (2016); Hosseini et al. (2013); Schepke et al. (2017); Wittneben et al. (2017); Erhan Comlekoglu et al. (2018)
PROMs	Santing et al. (2013); Nothdurft et al. (2014); Vanlioglu et al. (2012); Carrillo de Albornoz et al. (2014); Baldini (2016); Fenner et al. (2016); Nilsson et al. (2017); Wannfors and Smedberg (1999); Schepke et al. (2017); Hosseini et al. (2011)

2015; Lops et al., 2016) or an endodontic file, reporting minimal or no changes (−0.2 to 0.7 mm) with similar outcomes when comparing different abutment materials (0–0.4 mm; Baldini et al. 2016; Carrillo de Albornoz et al., 2014; Zembic et al., 2009).

The height of the interproximal papilla was assessed by means of the Jemt index (Jemt, 1997) in nine investigations (Baldini et al. 2016; Brown & Payne, 2011; Cardaropoli et al., 2006; Carrillo de Albornoz et al., 2014; Fenner et al., 2016; Henriksson & Jemt, 2003; Santing et al., 2013; Thoma et al., 2016; Zembic et al., 2013), or by measuring this papilla height in study casts in one study (Gallucci et al., 2011). In general, a papilla height increase was reported between the moment of placing the definitive crown and the end of the follow-up. The comparisons among the different abutment materials have rendered heterogeneous results, with one study reporting higher papilla index for titanium when comparing to zirconia abutments (Baldini et al. 2016), vs. another study reporting exactly the opposite (Carrillo de Albornoz et al., 2014), or other one reporting no differences irrespective of the abutment material (Zembic et al., 2013).

Colour

The colour of the peri-implant mucosa was assessed objectively by means of a spectrophotometer in one investigation (Zembic et al., 2009) reporting that both titanium and zirconia abutments induced visible differences when comparing with the natural teeth at 1 and

TABLE 7 Biological complications

Reference	Main findings
Tawse-Smith et al. (2017)	No implants presented bone loss >1 mm
Cardaropoli et al. (2006)	1 patient presented mucositis
Santing et al. (2013)	1 implant presented bone loss >2 mm
Bae et al. (2008)	0 cases of peri-implant infection
Henriksson and Jemt (2003)	It is mentioned that there were no signs of peri-implant infection and that bone loss was between 1 and 2 mm
Nothdurft and Pospiech (2010)	It is not specified the cases with peri-implantitis, but 7 implants lost more than 2 mm
Vanlioglu et al. (2012)	No single case with bone loss >0.5 mm
Hosseini et al. (2013)	2 buccal fistulas in the zirconia group without bone loss. 1 implant in the gold group presented bone loss of 2.5 mm. 2 buccal fistulas in the gold group without bone loss. 1 implant with suppuration in the gold group without bone loss
Thoma et al. (2016)	No bone loss >1 mm
Zembic et al. (2013)	5.5% of patients and 7.1% of implants presented peri-implantitis and implants were lost (two supporting zirconia abutments and one a titanium abutment)
Lops et al. (2013)	One implant presented mucositis and was successfully treated
Carrillo de Albornoz et al. (2014)	0 cases with peri-implantitis
Nilsson et al. (2017)	4 cases with peri-implantitis
Wannfors and Smedberg (1999)	1 patient presented early bone loss and another patient presented one implant with a fistula at 1 year
Schepke et al. (2017)	All implants were healthy
Hosseini et al. (2011)	3 patients in the test group presented suppuration without bone loss and 3 patients in the control group suppuration +PD ≥5 mm without bone loss

3 years (3 years: ΔE_{ZrO2} 9.3 [*SD* = 3.8]; ΔE_{Ti} 6.8 [*SD* = 3.8]); however, there were no differences among the different abutment materials at any time point.

Aesthetic indices

The evaluation of aesthetic outcomes was carried out in ten studies using different indices. The Pink Aesthetic Score (PES; Furhauser et al., 2005), which only assesses the soft tissues, was used in two studies (Erhan Comlekoglu et al., 2018; Schepke et al., 2017), demonstrating improvement in these scores after 1 year in one study (Schepke et al., 2017), while in the other the results were opposite, as they reported slight worsening 8 months after loading (Erhan Comlekoglu et al., 2018). In both cases, no differences were reported when comparing customized vs. prefabricated abutments.

The Pink and White Aesthetic Score (Belser et al., 2009), which evaluates both the aesthetics of the mucosa and the restoration, was used in one study comparing different abutment fabrication methods (Wittneben et al., 2017) and in a CS (Santing et al., 2013). No significant differences between groups were reported at 12 months (15.28 for prefabricated abutments and 16.15 for customized).

The Implant Crown Aesthetic Index (ICAI; Meijer, Stellingsma, Meijndert, & Raghoebar, 2005), which assesses both the aesthetics of soft and hard tissues in comparison with the adjacent teeth, was used in two studies comparing different abutment materials (Baldini et al. 2016; Carrillo de Albornoz et al., 2014) and in one CS (Santing et al., 2013). No significant differences were detected between groups, although the first study reported a clear tendency for better outcomes when zirconia was compared with titanium abutments, both for colour and for surface of the mucosa. For the CS, the mucosa was rated as excellent in 1.7% of the cases and as satisfactory in 65%, whereas the values for the crown were 3.3% and 71.7%, respectively.

The Copenhagen Index Score (CIS; Dueled, Gotfredsen, Trab Damsgaard, & Hede, 2009) is a composite index that evaluates the soft tissues, the crown morphology and the colour matching. Two studies used it to compare different abutment materials (Hosseini et al., 2011, 2013), and no significant differences were detected among groups in the overall score, although there was a tendency for better outcomes when zirconia abutments were used (Hosseini et al., 2013).

In addition, two studies scored the aesthetic outcomes through the subjective professional evaluation. In one investigation, all the restorations in both the test and control groups were rated as excellent or good at 5 years of follow-up (Andersson et al., 2003), whereas in the other the values were 100% in the test and 97% in the control group after 3 years (Andersson et al. 2001).

Technical complications

The incidence of technical complications was assessed in all but five studies (Calvo Guirado et al., 2007; Cardaropoli et al., 2006; Ferrari et al., 2015; Gallucci et al., 2011; Tawse-Smith et al., 2017) with a total cumulative incidence of complications of 7.9% (Table 8). In the controlled studies, the incidence of complications was slightly

TABLE 8 Technical complications reported in the included studies

Reference	Unit of analysis	Follow-up	% Complications test	% Complications control	Specifications of complications
Andersson et al. (1999)	Patient	24	5.26	0	AF
Andersson et al. (2001)	NR	36	5.88	0	AF
Andersson et al. (2003)	Patient	60	5.26	0	VF
Bae et al. (2008)	Implant	12	0		
Baldini et al. (2016)	Patient	12	0	0	
Brown and Payne (2011)	Patient	12	15.4		VF
Carrillo de Albornoz et al. (2014)	Patient	12	18.18	0	AF
Chen et al. (2008)	Implant	23	11.111	17.64	AF, CF
Erhan Comlekoglu et al. (2018)	Patient	24	0		
Fenner et al. (2016)	Patient	86	7.69	13.333	VC
Glauser et al. (2004)	Patient	49.2	13.9		SL, VC
Henriksson and Jemt (2003)	Implant	12	0		AF
Hosseini et al. (2011)	Implant	12	0	5.4	VC, LR
Hosseini et al. (2013)	Implant	36	1.92	9.52	VC, LR, CA
Lops et al. (2013)	Implant	60	13.51	9.09	VC, SL
Lops et al. (2016)	Implant	24	7.14	0	AF
Nilsson et al. (2017)	Implant	54	12.5		VC, AF
Nothdurft and Pospiech (2010)	Implant	12	10		VF
Nothdurft et al. (2014)	Implant	36	26.3		VF, AR
Santing et al. (2013)	Patient	18	1.6		VF
Schepke et al. (2017)	Patient	12	0		
Thoma et al. (2016)	Patient	14.8	20	30	VC, AF
Vanlioglu et al. (2012)	Implant	60			SL
Vigolo et al. (2006)	Implant	48	0	0	
Wannfors and Smedberg (1999)	Implant	36	40.47	2.94	SL, VC
Wittneben et al. (2017)	Patient	12	5.26		CF
Zembic et al. (2009)	Implant	36	0	20	Minor VC
Zembic et al. (2013)	Implant	67.2	0	30	Minor VC

Note. AF: abutment fracture; AR: abutment rotation; CA: crown adaptation problems; CF: crown fracture; LR: loss of retention; SL: screw loosening; VC: veneer chipping; VF: veneer fracture.

greater in the test groups than in the titanium group (8.7% and 5.9%, respectively), but without statistically significant differences, irrespective of the material used (RR = 1.27; 95% IC [0.64; 2.53]; $p = 0.490$; Figure 4).

Patient-reported outcome measures (PROMs)

Finally, PROMs were reported in 11 investigations. The patient's aesthetic perception was evaluated by means of a visual analogue scale (VAS) in six studies (Baldini et al. 2016; Carrillo de Albornoz et al., 2014; Fenner et al., 2016; Hosseini et al., 2011; Nilsson et al., 2017; Schepke et al., 2017) and by means of a questionnaire in four (Hosseini et al., 2013; Santing et al., 2013; Vanlioglu et al., 2012; Wannfors & Smedberg, 1999). In addition, one study reported that all patients were satisfied with their restoration (Nothdurft et al., 2014). In general, patients were highly satisfied with their implant-supported prosthesis and no differences could be attributed to the abutment materials.

4 | DISCUSSION

The results from this systematic review, where the primary aim was to assess which is the most suitable material for implant prosthetic abutments, have shown that there were no significant differences in regard to the main outcome measure (the changes in MBLs) when titanium was compared with different abutment materials. However, when changes in MBL were assessed over time, a significant loss occurred with all materials, except for titanium nitride. The magnitude of this loss with a mean follow-up of 30 months (WMD = 0.26 mm; range: 0.06–0.62), however, has limited clinical significance as it is

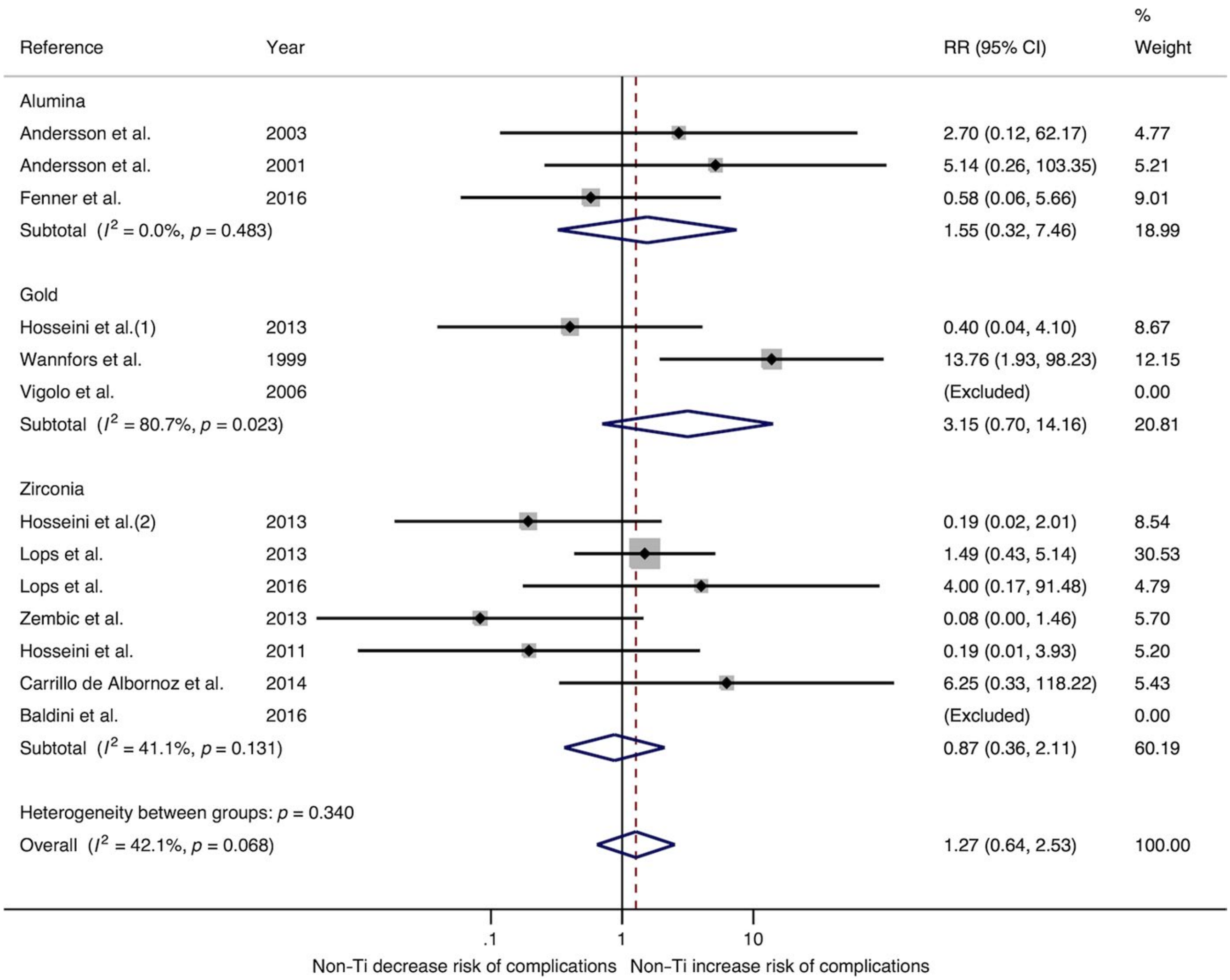

FIGURE 4 Forest plot for the risk of technical complications for the different abutment materials compared to titanium

smaller than the mean error of repeated radiographic measurements (Christiaens et al., 2018; De Smet, Jacobs, Gijbels, & Naert, 2002; Meijer, Steen, & Bosman, 1993).

This lack of significant differences when comparing the changes in MBL among the different abutment materials has also been reported in a recently published systematic review (Linkevicius & Vaitelis, 2015) as well as in experimental in vivo studies, where different abutment materials have resulted in similar histological outcomes by means of histomorphometric evaluation of the peri-implant hard tissues (Blanco et al., 2016; Mehl et al., 2016).

With regard to the secondary outcomes evaluated, namely, the changes in the peri-implant health outcomes, similarly, the abutment material had no influence on the changes in PD, although titanium abutments showed greater increase in BOP when compared to zirconia. The results from the case series also reported that abutments alternative to titanium underwent minor changes in these secondary outcomes. These results are in agreement with those reported in a recently published systematic review from our research group evaluating the effect of abutment characteristics (the macroscopic design, surface roughness and the manipulation method) on peri-implant soft tissue health, which mainly focused on bleeding (Sanz-Martín et al., 2017). The present systematic review, however, selected as primary outcome the changes in peri-implant bone levels and included both controlled studies and case series.

The tendency to greater plaque accumulation in the titanium group, although not significant (p = 0.06), might explain the higher mucosal inflammation reported around titanium when compared to zirconia. In vitro studies have reported less plaque accumulation in zirconia when compared to titanium surfaces (de Avila, Avila-Campos, Vergani, Spolidorio, & Mollo Fde, 2016; Roehling et al., 2017). When evaluating gold surfaces, due to its stability and low surface energy, less plaque accumulation has been reported (Yamane et al., 2013), although other factors, such as surface roughness, may exert a greater influence on bacterial adhesion (Burgers et al., 2010), which may explain the increase in BOP values reported in this systematic review associated with gold abutment surfaces. Moreover, experimental investigations have reported an apical shift of the barrier epithelium and subsequent marginal bone loss associated with abutments made of gold alloys (Abrahamsson et al., 1998; Welander et al., 2008).

Although ceramic abutments resulted in improved soft tissue outcomes (plaque and BOP) when compared to the titanium, this did not translate into significantly higher changes in MBL in the titanium group. This outcome may be explained by the length of the follow-up in the selected investigations, which ranged between 6 and 67 months, with more than half of the studies reporting radiographic changes of <2 years, which may be insufficient to develop significant bone loss, as it has been recently reported in an epidemiological study that the mean onset of peri-implantitis occurs within 3 years of function (Derks et al., 2016). Moreover, other factors apart from plaque accumulation and the ensuing inflammation may influence the onset of peri-implantitis (Jepsen et al., 2015; Tonetti et al., 2015). In fact, this systematic review found an overall low incidence of biological complications, although this outcome is difficult to interpret as the different studies have used different case definitions (Derks & Tomasi, 2015). In a European workshop, a threshold of 1.5–2 mm of bone loss in prospective studies was proposed to define a peri-implantitis case (Sanz & Chapple, 2012).

Another important factor for abutment material selection is its possible impact on the aesthetic outcome of the implant-supported final restoration. In this systematic review, the selected studies have used different aesthetic indices, and both the professional's perspective and patient's perspective have been evaluated. This heterogeneity may be the reason for the similarity in the reported results when comparing the different abutment materials to titanium. These results differ from those published by Linkevicius & Vaitelis (2015) because in the present systematic review, investigations not evaluating changes in peri-implant bone levels were excluded. Some of these studies specifically focusing on the aesthetic outcomes of different abutment materials and using objective methods, such as the spectrophotometer, have reported significant benefits when using ceramic abutments, mainly on the colour appearance of the peri-implant soft tissues (Bressan et al., 2011; Cosgarea et al., 2015; Martinez-Rus et al., 2017; Sala, Bascones-Martinez, & Carrillo de Albornoz, 2017). Similarly, the peri-implant mucosal thickness is of importance to render pleasing results, as it has been shown that abutment material evokes minimal colour changes in thicker tissues (>3 mm; Jung et al., 2008; Jung, Sailer, Hammerle, Attin, & Schmidlin, 2007).

The outcome of technical complications was low (<7.9%) and mainly due to veneer chipping and abutment fracture. This systematic review found higher but nonsignificant incidence of complications (RR = 1.27) for ceramic when compared to titanium abutments. The inherent properties of ceramic materials, with lower resistance to fracture and lesser flexural strength when compared to metal abutments, may explain these findings (Miyazaki, Nakamura, Matsumura, Ban, & Kobayashi, 2013). The risk of abutment fracture, however, is also related to the thickness of the material (Park, Phark & Chee, 2017; Zandparsa & Albosefi, 2016) and ultimately to the position and angulation of the implant with respect to the final restoration (Albosefi, Finkelman, & Zandparsa, 2014; Thulasidas et al., 2015). Metal interfaces within the ceramic abutments have been proposed as a means to reduce these complications (Mieda et al., 2017; Truninger et al., 2012). To prevent veneer chipping, improvement of adhesion methods and the advent of new ceramic materials hold the promise of minimizing these events (Blatz et al., 2010; Trindade, Amaral, Melo, Bottino, & Valandro, 2013). Alternatives such as monolithic restorations (Hamza & Sherif, 2017; Joda, Burki, Bethge, Bragger, & Zysset, 2015) and hybrid structures (Ferrari et al., 2014; Grohmann, Bindl, Hammerle, Mehl, & Sailer, 2015; Kanat et al., 2014) have also been proposed.

This systematic review may have some limitations, namely, the inclusion of study designs assessing different levels of evidence (RCT, CCT and prospective case series), although, to diminish the possible bias from the CS, independent meta-analyses were performed on the controlled studies. Furthermore, the methods to assess both the main and secondary outcomes (radiographic and clinical methods, as well as the different indices used to evaluate the changes in the soft tissues and the aesthetic outcomes) were so varied and heterogeneous that the results from the meta-analyses may not reflect the real outcomes. We therefore recommend future clinical trials using objective and standardized methods to assess the changes in both the hard and soft peri-implant tissues.

In conclusion, and considering these limitations, the results from this systematic review and meta-analysis have shown that different abutment materials had no significant impact on bone loss when compared to titanium and that marginal bone levels remained stable in the prospective studies. In contrast, titanium abutments demonstrated higher inflammatory response through increased BOP values over time when compared to the zirconia abutments.

CONFLICT OF INTEREST

The authors have stated explicitly that there are no conflict of interests in connection with this article.

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SUPPORTING INFORMATION

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