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REVIEW ARTICLE

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The effect of different abutment materials on peri-implant tissues—A systematic review and meta-analysis

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Abstract

Objectives: In patients with dental implants, what is the effect of transmucosal components made of materials other than titanium (alloys) compared to titanium (alloys) on the surrounding peri-implant tissues after at least 1 year?

Materials and Methods: This systematic review included eligible randomized controlled trials identified through an electronic search (Medline, Embase and Web of Science) comparing alternative abutment materials versus titanium (alloy) abutments with a minimum follow-up of 1 year and including at least 10 patients/group. Primary outcomes were peri-implant marginal bone level (MBL) and probing depth (PD), these were evaluated based on meta-analyses. Abutment survival, biological and technical complications and aesthetic outcomes were the secondary outcomes. The risk of bias was assessed with the RoB2-tool. This review is registered in PROSPERO with the number (CRD42022376487).

Results: From 5129 titles, 580 abstracts were selected, and 111 full-text articles were screened. Finally, 12 articles could be included. Concerning the primary outcomes (MBL and PD), no differences could be seen between titanium abutment and zirconia or alumina abutments, not after 1 year (MBL: zirconia: MD = −0.24, 95% CI: −0.65 to 0.16, alumina: MD = −0.06, 95% CI: −0.29 to 0.17) (PD: zirconia: MD = −0.06, 95% CI: −0.41 to 0.30, alumina: MD = −0.29, 95% CI: −0.96 to 0.38), nor after 5 years. Additionally, no differences were found concerning the biological complications and aesthetic outcomes. The most important technical finding was abutment fracture in the ceramic group and chipping of the veneering material.

Conclusions: Biologically, titanium and zirconia abutments seem to function equally up to 5 years after placement.

KEYWORDS
dental abutment, implant abutment, marginal bone level, meta-analysis, yttria stabilized tetragonal zirconia, zirconium oxide

1 | INTRODUCTION

Successful integration of an implant into the surrounding peri-implant tissues is situated on two levels: osteo-integration and muco-integration. Although the first is largely dependent on the characteristics of the implant, the latter is mainly affected by the transmucosal component/abutment and its characteristics. The implant-abutment connection, the number of abutment disconnections, the height of the abutment, its emergence angle and its material all influence the surrounding soft tissues (Laleman & Lambert, 2023).

Currently, a plethora of materials are available to fabricate implants and abutments, such as metals, ceramics and composites (Linkevicius & Vaitelis, 2015). Each of these materials has its benefits and shortcomings regarding biocompatibility, long-term stability and aesthetics.

For decades, titanium was the preferred implant and abutment material, based on its many advantages such as excellent biocompatibility, material strength and resistance to distortion (Linkevicius & Vaitelis, 2015). Its most important disadvantage is that its color may show through the gingiva, causing an unaesthetic grayish discoloration (Jung et al., 2007).

Based on their tooth-like color, ceramics like alumina or zirconia seem interesting alternatives to titanium from an aesthetic point of view (Glauser et al., 2004; Jung et al., 2008). Additionally, they show similar properties as titanium regarding biocompatibility and less plaque-accumulation (de Avila et al., 2016; Rimondini et al., 2002). But, they are brittle and prone to fatigue and thus less resistant to fractures (Apicella et al., 2011; Belser et al., 2004).

The available systematic reviews regarding implant/abutment materials focus mainly on survival and technical complications (Fiorillo et al., 2022; Hu et al., 2019; Pjetursson et al., 2018; Roehling et al., 2018; Sailer et al., 2018) or on aesthetic outcomes (de Moura Costa et al., 2021). Less information is available about the biological impact of different materials (Sanz-Martín et al., 2018). The envisaged focused question for this invited review for the 2023 ITI consensus meeting was, therefore: "In clinical studies, what other materials compared to commercially pure titanium, or a specific titanium alloy allow peri-implant soft and hard tissue integration?" However, the available studies on this subject were too heterogeneous making it impossible to combine information regarding implants and abutments. The main limiting factor is that there are several randomized controlled clinical trials available about the abutment materials, while this is not the case for the implant materials.

This focused question was thus answered in two separate systematic reviews. One focused on the effect of implant materials on the peri-implant tissues in clinical trials (here, we want to cite the other systematic review about implants: Roehling S. et al., 2023). The current systematic review examined the effect of different abutment materials, directly compared to commercially pure titanium or a specific titanium alloy on peri-implant tissues based on randomized controlled trials.

2 | MATERIALS AND METHODS

This systematic review was conducted according to the Preferred Reporting Items for Systematic review and Meta-Analysis Protocols (PRISMA-P) (Page et al., 2021) statement using the Population, Intervention, Comparison and Outcome (PICO) method (Schardt et al., 2007). The protocol for this systematic review was registered on PROSPERO with the number (CRD42022376487).

2.1 | Focused question

The focused question of this systematic review was: "In patients with dental implants, what is the effect of transmucosal components made of materials other than titanium(alloys) compared to titanium(alloys) on marginal bone level, pocket depth, abutment survival, technical and biological complications and esthetic outcomes after at least 1 year?"

This led to the following PICOT-question:

- Patients: patients with dental implants.
- Intervention: abutments in materials different from titanium (alloys).
- Comparison: titanium(alloy) abutments.
- Outcome: marginal bone level, pocket probing depth, abutment survival, biological and technical complications and esthetic outcomes.
- Time: at least 1-year follow-up.

2.2 | Search strategy

An electronic, systematic search of Medline via Pubmed, Embase via Elsevier and Web of Science via Clarivate databases was performed in July 2022. The specific search terms can be found in Appendix S1.

Additional hand searches were performed and included the following: (1) bibliographies of previous reviews on the subject and (2) bibliographies of all included full-text articles.

2.3 | Eligibility criteria

The following inclusion criteria were defined:

- Human studies published after January 2000.
- Randomized clinical trials.
- At least 10 patients/group at follow-up.
- Control: abutments consisting of titanium (alloy).
- Intervention: abutments made of 1 material alternative to titanium (alloy).
- Follow up for at least 12 months after implant placement.
- Outcomes reporting details about peri-implant marginal bone level and/or pocket probing depth.
- Language: English.

The following exclusion criteria were defined:

- Transmucosal components for which we can assume with high certainty that different materials are in contact with the surrounding soft tissues.
- Different macroscopic designs between control and intervention group.
- Studies focusing on the effect of different implant-abutment connections, different surgical approaches, different loading protocol, etc.
- Studies in other languages than English (due to the time limitations of this invited review).

2.4 | Selection of studies

After elimination of duplicates, the reviewers (SR, IL) independently screened titles, abstracts and full texts. For the screening of titles and abstracts, the free web and mobile app Rayyan (http://rayyan.qcri.org) was used (Ouzzani et al., 2016). If the decision was unclear after title screening, these articles were included in the abstract screening. If titles or abstracts did not provide sufficient information for selection, full texts were obtained. Any disagreement regarding inclusion and exclusion was resolved by discussion between the reviewers. To evaluate the agreement between the reviewers, Cohen's kappa coefficient (κ) was calculated for title and abstract selection (Landis & Koch, 1977).

2.5 | Data extraction and outcome measures

Peri-implant marginal bone level (MBL) and probing depth (PD) were the primary outcome. Secondary outcomes included abutment survival, technical and biological complications and esthetic outcomes.

Marginal bone level is the distance from the implant-abutment interface to the marginal bone.

Abutment survival was defined as the original abutment (with or without modifications) still in place for the observation period.

The **biological complications** included bone loss of more than 2mm over the observation periods, soft tissue complications (swelling, suppuration, fistulas, mucositis, etc.) and peri-implantitis. Also, peri-implant PD were extracted.

Technical complications were classified based on the framework proposed by Lang et al. (2012) (Lang et al., 2012). They were classified as major complications if replacement of the restoration was needed due to implant fracture or loss of the supra-structures. Abutment fracture, veneer or framework fracture, phonetic complications were seen as medium complications. And minor complications were defined as complications that could be corrected with small efforts, such as abutment and screw loosening, loss of retention, debonding, loss of screw hole sealing, veneer chipping (to be polished) and occlusal adjustment.

All **aesthetic outcomes** reported in the included articles were extracted. On one hand those based on standardized indices/measurement methods and/or devices by the examiners, and on the other hand patient-reported aesthetic outcomes.

Data extraction by the reviewers was independently performed for all included studies (SR, IL) using data extraction tables. Disagreement regarding data extraction was resolved by discussion.

From the included clinical full-text articles, the following data were extracted: author(s), year of publication, study design (parallel versus split-mouth), setting (university versus private practice), follow-up period, abutment materials, number of included patients and abutments, number of dropouts, type of prosthetic restoration (single crown (SC)/fixed dental partials (FDP)) and retention modes of the crown/bridges (cement-retained (CR)/screw-retained (SR)).

2.6 | Risk of bias

Two reviewers (SR and IL) independently assessed the risk of bias of the included studies according to the RoB2 tool (Sterne et al., 2019). This was based on the outcomes for MBL.

2.7 | Statistical analysis

For rate ratios of survival rates and mean differences in MBL and probing depth between treatment and control group after 1 and 5 years, DerSimonian–Laird random-effect meta-analyses were performed using meta in Stata statistical software version 17.0 (StataCorp LLC). The amount of heterogeneity across studies was assessed with the I^2 measure. For the survival rates, exact binomial 95%-confidence intervals were calculated. As the survival rates are at 1 in some studies, we added 0.5 to all cells of studies with at least one zero cell to include such studies in the pooled estimate. Robustness checks using the Freeman-Tukey double arcsine transformation yield very similar results. For MBL and probing depth, 95%-confidence intervals for means were calculated based on the reported standard deviations.

Forest plots were used for graphic presentation of the rate ratios of survival rates and mean differences in MBL and probing depth in the treatment and control group in each study with confidence intervals along with the overall pooled prevalence. In the graphs, the weight of each study to the meta-analyses is represented by the area of a box whose center represents the size of the effect estimated from that study. The confidence interval for the effect from each study is also shown. The summary effect is shown by the middle of a diamond whose left and right extremes represent the corresponding confidence interval.

3 | RESULTS

The electronic database search resulted in 7718 publications (Pubmed: 4972; Embase: 1981; Web of Science: 1665). After removal of duplicates, 5129 titles were available and screened resulting in 580 abstracts for further evaluation. After screening the abstracts, a total of 111 publications were selected for full-text evaluation. After analysis of the included full-text articles, a total of 12 clinical studies fulfilled the inclusion criteria and were included in the qualitative and quantitative analyses for this focused PICOT question (Figure 1).The inter-examiner agreement was κ = 0.82.

3.1 | Study characteristics

Thirteen studies comparing different abutment materials with titanium abutments were included for data extraction (Andersson et al., 2001, 2003; Baldini et al., 2016; Carrillo de Albornoz et al., 2014; Fenner et al., 2016; Ferrari et al., 2015; Hosseini et al., 2011, 2022; Sailer, Zembic, et al., 2009; Vigolo et al., 2006; Zembic et al., 2009, 2013). These reported on 10 original investigations. Sailer et al., 2009, Zembic et al., 2009 and Zembic et al., 2013 included the same patient population at different time points, just like Hosseini et al., 2022 described the 5-year follow-up of the same patient group described after 1 year in Hosseini et al., 2011. Most of the articles (9 out of 12) compared titanium abutments with zirconia abutments, 3 examined titanium versus alumina abutments and 2 titanium versus gold. All except one study examined a pair-wise comparison, Fenner et al., 2016 examined three different abutment materials. More study details are described in Table 1.

3.2 | Peri-implant marginal bone loss

Figure 2 shows the meta-analyses in terms of marginal bone loss. After 1 year the mean marginal bone loss around implants was not statistically different between implants with zirconia or titanium abutments (MD = −0.24, 95% CI: −0.65 to 0.16 based on four studies and 151 abutments). Just as no difference could be found between implants with alumina versus titanium abutments (MD = −0.06, 95% CI: −0.29 to 0.17 based on 2 studies and 101 abutments). These findings carry over to the five-year data where no differences could be examined between zirconia and titanium (MD = 0.21, 95% CI: −0.22 to 0.65 based on 2 studies and 91 abutments) and neither between alumina and titanium (MD = −0.04, 95% CI: −0.32 to 0.25 based on 2 studies and 115 abutments).

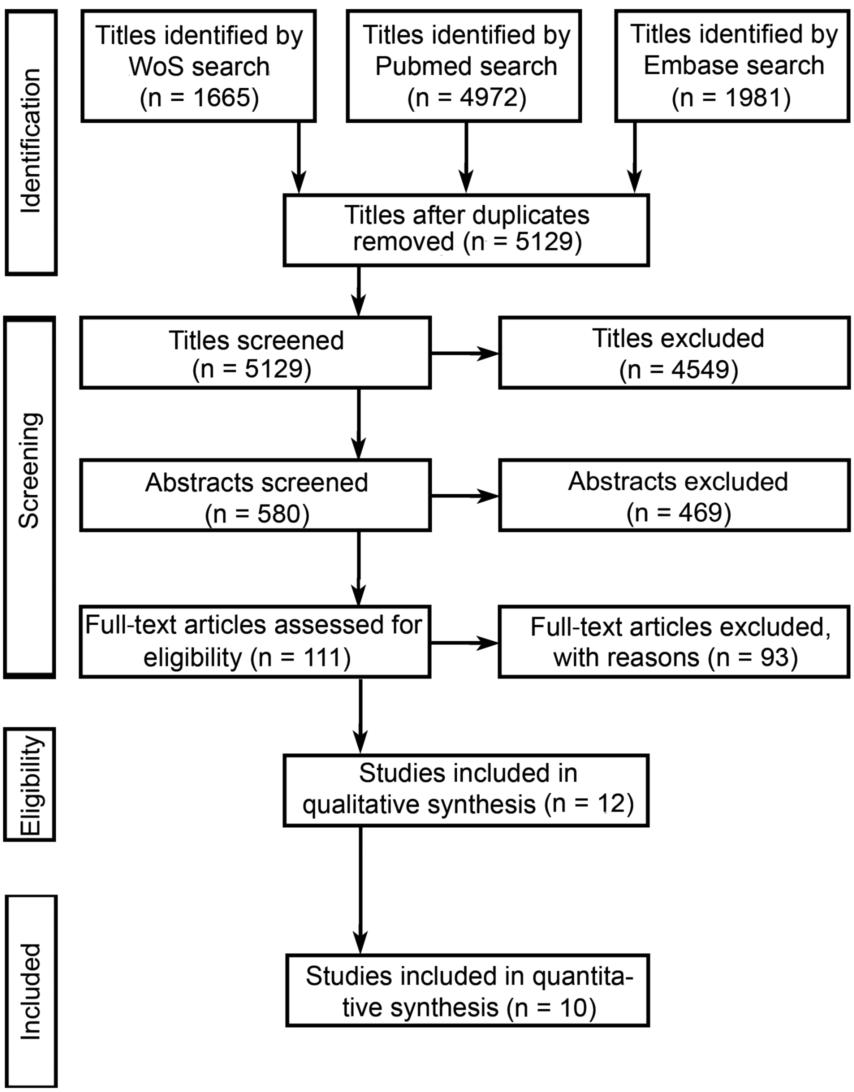

FIGURE 1 PRISMA flow diagram.

TABLE 1 Descriptive characteristics of RCTs investigating abutments.

Author/year	Study design setting	Follow up (mo)	Control abutment	Test abutment	No of patients (BL)	No of abutments c/t (BL c/t)	Prosthetics	Screw-retained versus cemented
Hosseini et al., 2022[a]	RCT, split-mouth and parallel University	60	Titanium (TiDesign, Astra Tech, Sweden)	Zirconia (ZirDesign, Astra Tech, Sweden)	30 (36)	32/31 (35/38)	SC	CR
Baldini et al., 2016	RCT, parallel University	12	Titanium (SPIEASY, Thommen)	Zirconia (SPIART, Thommen)	24	12/10 (12/12)	SC	CR
Fenner et al., 2016	RCT, split-mouth NR	60	Titanium abutments (synOcta cementable abutment, Straumann)	Aluminum oxide-based (Al_2O_3) abutments (synOcta In-Ceram blank, Straumann)	28	20/16	SC	SR/CR
Ferrari et al., 2015	RCT, parallel University	24	Titanium	Gold-hue titanium/titanium nitride OR Zirconia (Atlantis)	47	15/18/14	SC	NR
Carrillo de Albornoz et al., 2014	RCT, parallel University	12	Titanium (SPIEASY, Thommen Medical AG, Grenchen, Switzerland)	Zirconia (SPIART, Thommen Medical AG, Grenchen, Switzerland)	25 (30)	14/11 (15/15)	SC	CR
Zembic et al., 2013	RCT NR	60	Titanium (Procera, Nobel Biocare AB, Carolinsk, Sweden)	Zirconia (Procera, Nobel Biocare AB, Carolinsk, Sweden)	18 (22)	10/18 (20/20)	SC	CR (2 SR)
Hosseini et al., 2011[a]	RCT, split-mouth and parallel University	12	Titanium (TiDesign, Astra Tech, Sweden)	Zirconia (ZirDesign, Astra Tech, Sweden)	36	35/38	SC	CR
Sailer et al., 2009[b]	RCT NR	12	Titanium (Procera, Nobel Biocare AB, Carolinsk, Sweden)	Zirconia (Procera, Nobel Biocare AB, Carolinsk, Sweden)	20 (22)	12/19 (20/20)	SC	CR (2 SR)
Zembic et al., 2009[b]	RCT NR	36	Titanium (Procera, Nobel Biocare AB, Carolinsk, Sweden)	Zirconia (Procera, Nobel Biocare AB, Carolinsk, Sweden)	18 (22)	10/18 (20/20)	SC	CR (2 SR)
Vigolo et al., 2006	RCT, split-mouth University	60	Titanium (Procera, NobelBiocare, Göteburg, Sweden)	Gold-alloy (gold, machined UCLA, SGUCA1C, 3i/Implant Innovations, Palm Beach Gardens, FL)	20	20/20	SC	CR
Andersson et al., 2003	RCT, parallel NR	48	Titanium abutment (CeraOne abutment, Nobel Biocare)	Sintered aluminum oxide abutment (CerAdept, Nobel Biocare)	30 (32)	39/40 (50/53)	Short-span FDPs	c: SR t: CR
Andersson et al., 2001	RCT, parallel NR	36	Titanium abutment (CeraOne abutment, Nobel Biocare)	Sintered aluminum oxide abutment (CerAdept, Nobel Biocare)	60	35/34 (35/30)	SC	c: CR t: CR/SR

Abbreviations: BL, baseline; c, control; CR, cemented crown; FDP, Fixed partial dentures; mo, months; NR, not reported; RCT, randomized controlled trial; SC, single crown; SR, screw retained crown; t, test.

[a]Examining the same patient population.

[b]Examining the same patient population.

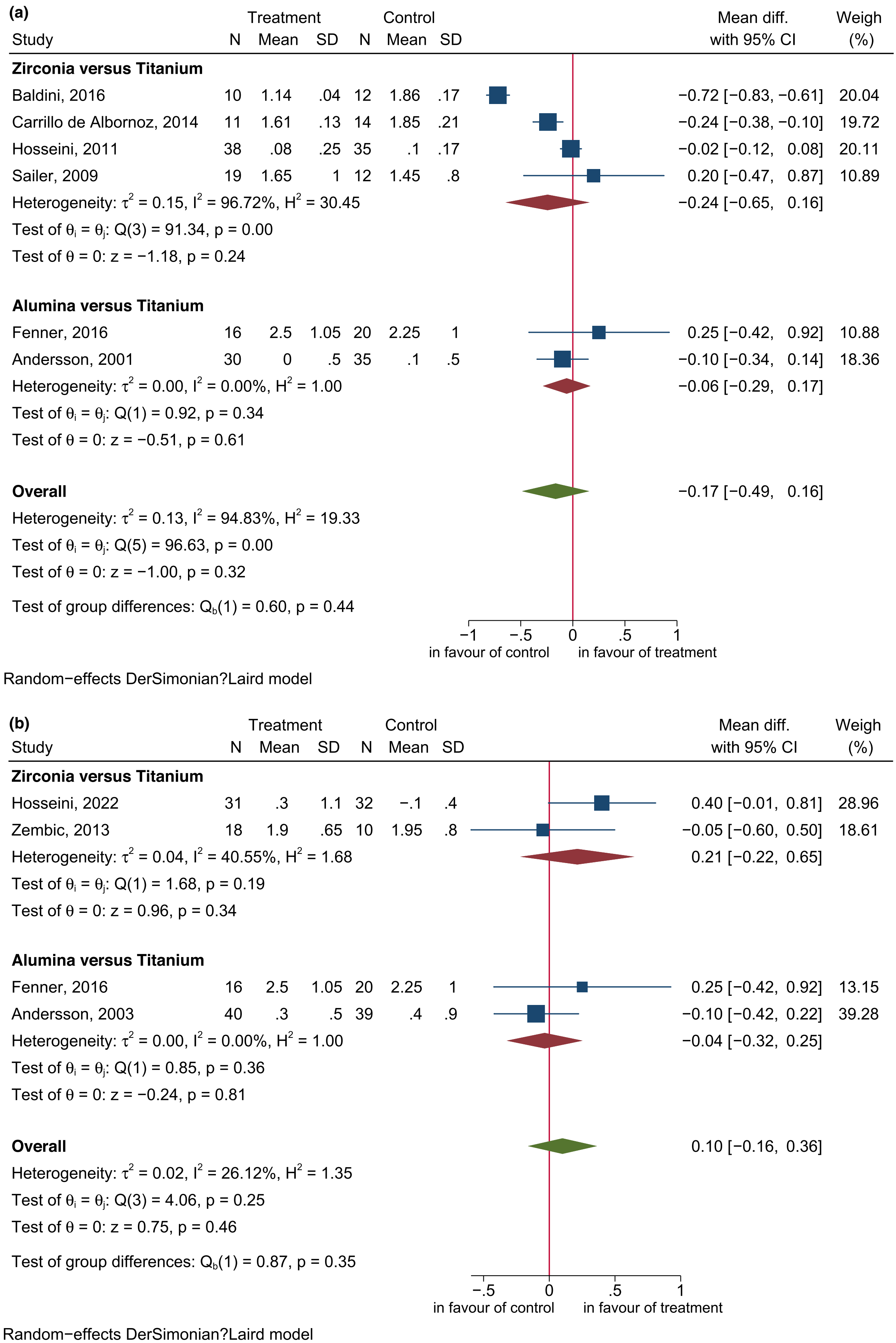

FIGURE 2 (a) 1-year marginal bone loss according to abutment material, (b) 5-year marginal bone loss according to abutment material.

3.3 | Peri-implant probing depths

The meta-analyses for pocket probing depth are shown in Figure 3. After 1 year the mean pocket probing depth around implants with zirconia abutments was not significantly different than around implants with titanium abutments (MD = −0.06, 95% CI: −0.41 to 0.30 based on 3 studies and 78 abutments). The same observations could be made for implants with alumina versus titanium abutments (MD = −0.29, 95% CI: −0.96 to 0.38 based on 1 study and 36 abutments). After 5 years, the results were comparable (respectively MD = −0.02, 95% CI: −0.38 to 0.34 based on 2 studies and 91 abutments and MD = −0.29, 95% CI: −0.96 to 0.38 based on 1 study and 36 abutments).

3.4 | Abutment survival

Figure 4 shows the forest plots for the pairwise meta-analyses in terms of survival rate of the abutment after 1- and 5-years. No differences could be found between titanium and zirconia or alumina.

3.5 | Biological complications

Table 2 summarizes all biological/clinical outcomes reported in the selected studies. In general, no differences could be found examining plaque, bleeding, pocket depth and marginal bone loss.

3.6 | Technical complications

Table 3 shows all details concerning technical complications separated in minor, medium and major complications.

The only major complication described in all the included studies was a crown fracture 2 years after loading in the study of Andersson et al., 2001 in the titanium abutment group (Andersson et al., 2001). The most common weakness seen with ceramic abutments was abutment fracture (Andersson et al., 2001, 2003; Carrillo de Albornoz et al., 2014).The most frequent (minor) complication was chipping of the veneering material (Hosseini et al., 2011, 2022; Sailer, Zembic, et al., 2009; Zembic et al., 2009, 2013).

3.7 | Esthetic outcomes

No statistical significant intergroup differences were found when between titanium and ceramic abutment materials concerning aesthetics. Not when this was measured by professionals (mostly based on the Implant Crown Aesthetic Index (Meijer et al., 2005) and Papilla index (Jemt, 1997)), nor when the patients were surveyed about their satisfaction (mostly based on VAS scales). Details are provided in Tables 4 and 5. Data about aesthetics and gold abutments were not reported.

3.8 | Risk of bias assessment

The risk of bias assessment based on the Cochrane Risk of Bias 2 tool showed some concerns of bias for all (Andersson et al., 2001, 2003; Baldini et al., 2016; Fenner et al., 2016; Hosseini et al., 2011, 2022; Sailer, Zembic, et al., 2009; Vigolo et al., 2006; Zembic et al., 2009, 2013) but two studies (Carrillo de Albornoz et al., 2014; Ferrari et al., 2015) (Table 6). This was most often based on concerns for risk of bias concerning randomization (e.g. often there was ambiguity about how the treatment allocation was concealed) and concerning missing outcome data (often it was unclear how missing outcome data impacted the final results).

4 | DISCUSSION

The present review showed a similar MBL, PD and abutment survival after 1- and 5-years of follow-up for abutments made of alternative materials compared to titanium abutments. Additionally, few biological and technical complications were reported. The included studies did not report differences concerning esthetics between titanium and ceramic abutments.

The abutment survival rates ranged from 83% (zirconia) to 100% (titanium) after 1 year. The 5-year data were even higher ranging from 93% (alumina) to 100% (zirconia). This can be due to attrition bias, since in the studies with 5-year follow-up the number of dropouts was noticeably higher than in the studies with 1-year follow-up. Moreover, caution should be exercised in interpreting this result. It seems that in most studies, the abutment fractures that occurred at the try-in or initial placement are usually not counted for the survival rate and were just replaced (Andersson et al., 2001, 2003). This problem of not taking into considerations problems that might have occurred over time with the abutment/reconstruction has also been reported in other systematic reviews (Pjetursson et al., 2018). And it is common knowledge that survival does not equal a successful treatment (Halim et al., 2022).

The only clinical parameter that could be analyzed for abutment materials in a meta-analysis was PD. The heterogeneity of the used indexes to measure plaque and bleeding on probing/ gingival health made a meta-analysis impossible. However, all but one studied reported no differences in plaque index, nor in bleeding/gingival indices. However, it seems that in the sole study reporting slightly more plaque on titanium than on zirconia abutments (Zembic et al., 2013) the specific *p*-value supporting this is lacking in the paper. Although this is in contrast to earlier studies examining plaque accumulation on disks showing less plaque accumulation to zirconia than to titanium (Rimondini et al., 2002; Scarano et al., 2004), these findings are in line with those of previously published systematic reviews based on clinical examinations (Linkevicius & Vaitelis, 2015; Totou et al., 2021). Similarly, Sanz-Sanchez and coworkers, did find a greater increase in bleeding on probing around titanium compared to zirconia abutments; however, this was based on a meta-analysis of solely three studies (Sanz-Sánchez et al., 2018).

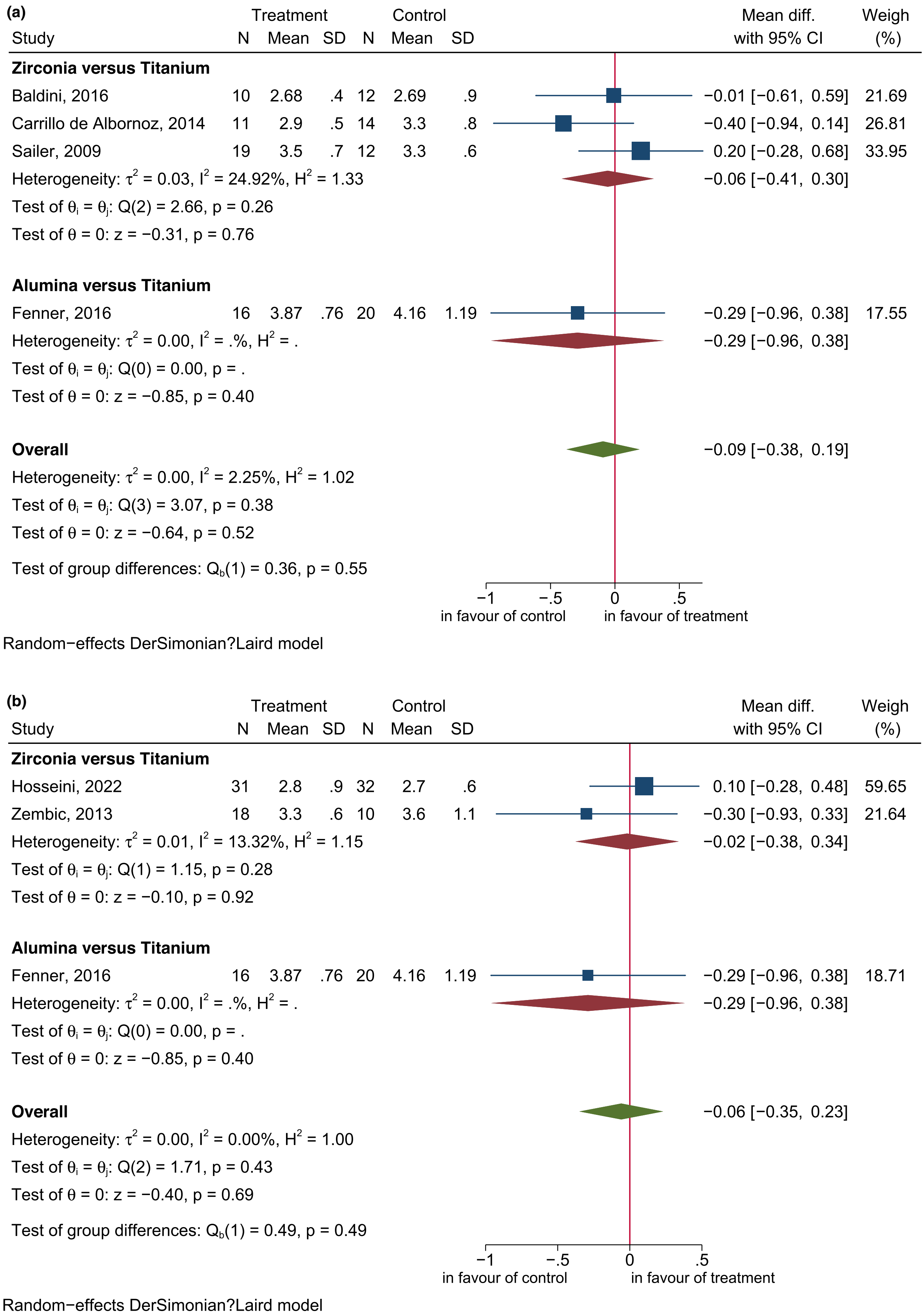

FIGURE 3 (a) Probing pockets depth (PD) values after 1 year according to abutment material, (b) Probing pockets depth (PD) values after 5 years according to abutment material.

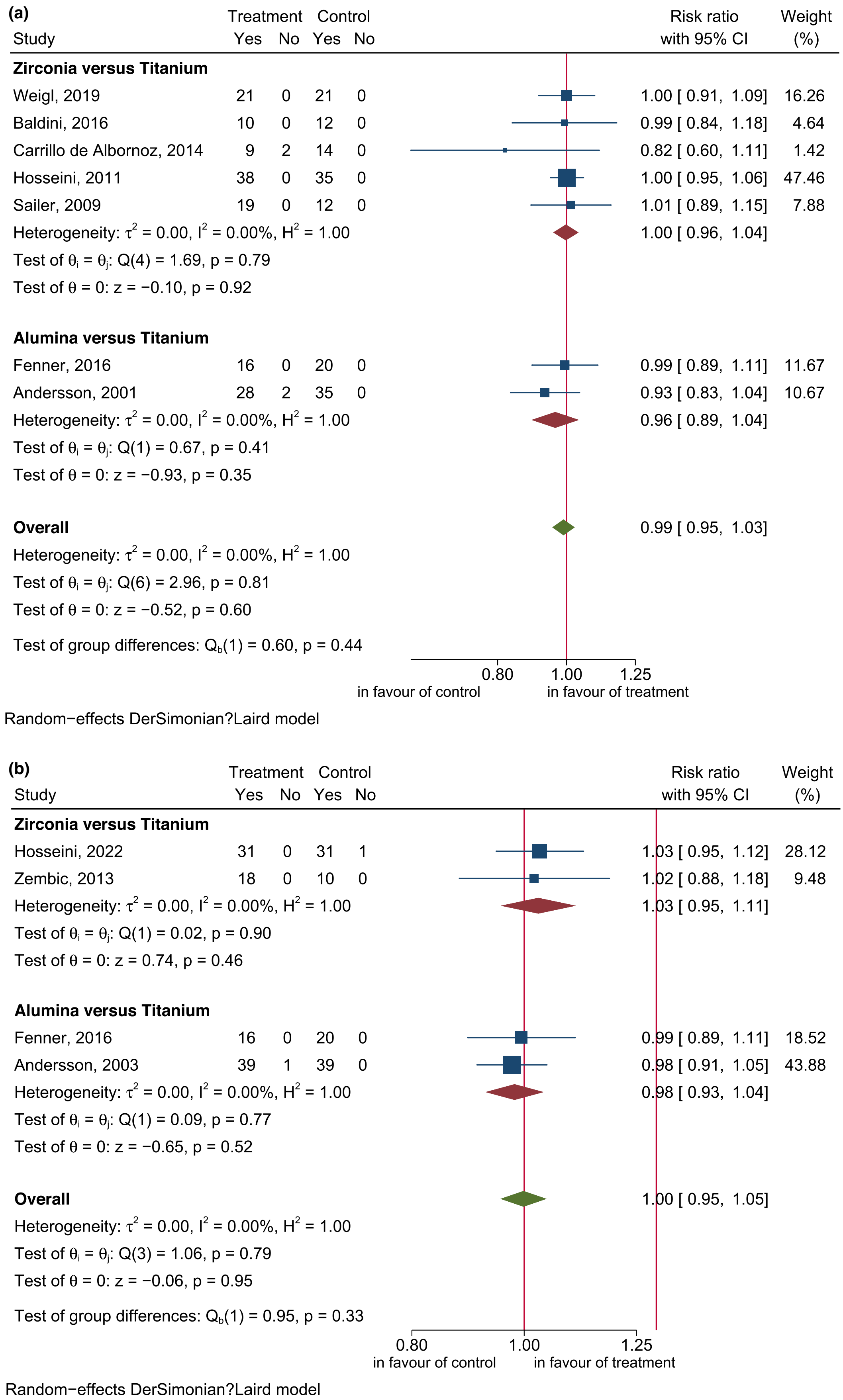

FIGURE 4 (a) 1 year survival rate of the abutments according to abutment material, (b) 5-year survival rate of the abutments according to abutment material.

TABLE 2 Biological complications of abutment studies.

Author/year	Follow up (mo)	Abutment type	Biological-clinical outcomes
Hosseini et al., 2022[a]	60	Titanium vs Zirconia	• No significant differences in mPI (p = .360) • No significant differences in mBI (p = .350) • 1 Zirconia implant with >2 mm bone loss • 1 Zirconia implant with PPD >5 mm • Peri-implant mucositis in 22.6% of the titanium restorations and 34.4% of the zirconia restorations
Baldini et al., 2016	12	Titanium vs Zirconia	• No significant differences regarding BoP (p = .6) • No significant differences regarding PPD (p = .8) • No significant differences regarding recession (p = .8) • MBL: mesially significantly more for titanium implants versus zirconia (p = .02)
Fenner et al., 2016	60	Titanium vs Aluminum oxide	• No significant differences in PI (p = .274) • No significant differences regarding BoP (p = .339) • No significant differences regarding PPD (p = .586) • The recession of the mucosa was statistically less significant in the aluminum oxide than in the titanium group (p = .002) • No significant differences in MBL
Ferrari et al., 2015	24	Titanium vs Gold-hue vs Zirconia	• MBL: significance NR
Carrillo de Albornoz et al., 2014	12	Titanium vs Zirconia	• No significant differences in FMPS (p-value NR) • No significant differences in FMBS (p-value NR) • No significant differences regarding PPD (p-value NR) • No significant differences in MBL (p = .430)
Zembic et al., 2013[b]	60	Titanium vs Zirconia	• Slightly more plaque on titanium than on zirconia abutments (p = .96) • No significant differences regarding BoP (p = .96) • No significant differences in mean PPD (p = .85) • No significant differences in MBL (MBL: p = .95, DBL: p = .99)
Hosseini et al., 2011[a]	12	Titanium vs Zirconia	• No significant differences in mPI (p-value NR) • No significant differences in mBI (p-value NR) • No significant differences in MBL (p = .69) • 3 implants with a titanium abutment with suppuration and PPD ≥5 mm • 1 implant with a zirconia abutment with marginal fistula • 3 implants with a zirconia abutment with suppuration upon probing • 2 implants with a zirconia abutment with PPD ≥5 mm • 1 implant with a zirconia abutment with continuous, weak pain
Sailer et al., 2009[b]	12	Titanium vs Zirconia	• No significant differences in PI (p-value NR) • No significant differences regarding BoP (p-value NR) • No significant differences regarding PPD (p-value NR)
Zembic et al., 2009[b]	36	Titanium vs Zirconia	• No significant differences in PCR (p-value NR) • No significant differences regarding BoP (p-value NR) • No significant differences regarding PPD (p-value NR) • No significant differences in MBL (p-value NR)
Vigolo et al., 2006	60	Titanium vs Gold-alloy	NR
Andersson et al., 2003	48	Titanium vs Alumina	• No significant differences for plaque (p > .05) • No significant differences for mucosal bleeding (p > .05) • 3 implants with an alumina abutment with PPD 5 mm • No significant differences in MBL (p > .3)
Andersson et al., 2001	36	Titanium vs Alumina	• No significant differences in presence of plaque (p-value NR) • No significant differences in mucosal/ginigival bleeding (p-value NR)

Abbreviations: BoP, bleeding on probing; FMBS, full mouth bleeding score; FMPS, full mouth plaque score; mBI, Sulcus Bleeding Index; MBL, marginal bone loss; mPI, modified Plaque Index; NR, not reported; PCR, plaque control record; PPD, probing pocket depth.

[a,b]Studies followed by the same letter were conducted on the same patient population.

TABLE 3 Technical complications of abutment studies (based on the framework proposed by Lang et al., 2012).

Author/year	Follow up (mo)	Abutment type	Abutment survival (%)	Major complications(requiring replacement of the restoration, such as, implant fracture, abutment tooth fracture, loss of supra-structures)	Medium complications (such as abutment fracture, veneer or framework fractures, phonetic complications)	Minor complications (to be corrected with small efforts; such as abutment and screw loosening, loss of retention, de-bonding, loss of screw hole sealing, veneer chipping (to be polished) and occlusal adjustment)
Hosseini et al., 2022[a]	60	Titanium	100	-	-	3 losses of retention (1 after 1 yr, 2 after 3 yrs) 1 ceramic veneering fractures
		Zirconia	100	-	-	1 ceramic veneering fractures
Baldini et al., 2016	12	Titanium	100	-	-	-
		Zirconia	100	-	-	-
Fenner et al., 2016	60	Titanium	100	-	-	-
		Aluminum oxide	100	-	-	-
Ferrari et al., 2015	24	Titanium	NR	NR	NR	NR
		Gold-hue	NR	NR	NR	NR
		Zirconia	NR	NR	NR	NR
Carrillo de Albornoz et al., 2014	12	Titanium	100	-	-	-
		Zirconia	83.3	-	2 abutments fractured when tightened at the required torque	-
Zembic et al., 2013[b]	60	Titanium	100	-	-	3 minor chippings of the veneering ceramic (at 6 and 12 mo, 5 yrs)
		Zirconia	100	-	-	-
Hosseini et al., 2011[a]	12	Titanium	100	-	-	1 loss of retention 1 chipping of veneering porcelain
		Zirconia	100	-	-	0
Sailer et al., 2009[b]	12	Titanium	100	-	-	2 minor chippings of the veneering ceramic (at 6 and 12 mo)
		Zirconia	100	-	-	-
Zembic et al., 2009[b]	36	Titanium	100	-	-	2 minor chippings of the veneering ceramic (at 6 and 12 mo)
		Zirconia	100	-	-	-
Vigolo et al., 2006	60	Titanium	100	-	-	-
		Gold-alloy	100	-	-	-
Andersson et al., 2003	60	Titanium	100	-	-	-
		Alumina	98.1	-	2 minor abutment fractures during initial prosthetic work (proshtetic treatment was continued) 1 abutment fracture	-

(Continues)

TABLE 3 (Continued)

Author/year	Follow up (mo)	Abutment type	Abutment survival (%)	Major complications(requiring replacement of the restoration, such as, implant fracture, abutment tooth fracture, loss of supra-structures)	Medium complications (such as abutment fracture, veneer or framework fractures, phonetic complications)	Minor complications (to be corrected with small efforts; such as abutment and screw loosening, loss of retention, de-bonding, loss of screw hole sealing, veneer chipping (to be polished) and occlusal adjustment)
Andersson et al., 2001	12	Titanium	100	-	-	-
		Alumina	93	-	5 abutments fractured during preparation or placement (were replaced) 2 minor chip fractures during placement 2 fractured after loading (1 and 7 mo)	-
	36	Titanium	100	Crown fracture after 2 years of loading	-	-
		Alumina	100	-	-	-

Abbreviations: Mo, months; NR, not reported; yr, year.

[a]Examining the same patient population.

[b]Examining the same patient population.

In all included studies, there were few technical complications. The ones that were reported were mainly chipping in the titanium abutment group and abutment fracture with the ceramic abutments. The latter can be explained by the inherent characteristics of ceramic materials, with lower fracture resistance as shown repeatedly in in vitro studies (Foong et al., 2013; Leutert et al., 2012; Mitsias et al., 2010). This is also affected by other abutment characteristic such as the angulation and thickness of the ceramic abutment (Park et al., 2017; Zandparsa & Albosefi, 2016) and the effect of (exorbitant) occlusal forces (Gou et al., 2019).

The esthetic outcomes seem comparable for the four examined materials. This is in contrast with animal data (Jung et al., 2007) and clinical data based on spectrophotometric data (Pitta et al., 2020; Totou et al., 2021). A sidenote has to be made that, although Pitta and co-workers found significantly better spectrophotometric data for ceramic abutments compared to the overall metal abutments, when comparing directly the data of titanium and zirconia abutments no significant differences could be found (Pitta et al., 2020). The thickness of the mucosa also plays an important role in this process (Bienz et al., 2022; Sala et al., 2017).

Although this systematic review failed to detect significant differences between the materials examined (titanium, zirconium, alumina and gold), we see that the data we were able to collect on alumina and gold are very limited and mostly at least 15 years old. Clinically, the use of these materials seems largely abandoned. The use of gold abutments has been discontinued due to the high pricing and the subpar biocompatibility compared to titanium (Abrahamsson et al., 1998; Furuhashi et al., 2021; Welander et al., 2008). The use of alumina has been replaced by the use of zirconia, since both have the same aesthetic and biological characteristics, but zirconia is a much stronger ceramic. The fracture toughness of Zirconia is 9 MPa $m^{1/2}$ (Sailer, Philipp, et al., 2009) versus 3.6 MPa $m^{1/2}$ (Guazzato et al., 2004) for alumina. Additionally, its bending strength (900 MPa) (Sailer, Philipp, et al., 2009) is double of the bending strength of alumina (440 MPa) (Guazzato et al., 2004).

There are certain shortcomings in the current literature investigating the influence of abutment materials, shortcomings that are therefore reflected in this systematic review. First, when interpreting these results, on must be aware that the meta-analyses are based on pooled data from different types of abutments. For example, this systematic review pooled implants placed in the anterior and posterior regions in the mouth.

Second, almost every included study used different indices for plaque, gingival health, bleeding, technical complications and aesthetics. This made summarizing the results very complex and made meta-analyses impossible for these parameters. In addition, it should be noted that even for the parameters for which a meta-analysis could be performed, sometimes only a limited number of articles could be included. There is thus a need for standardized reporting concerning peri-implant health and disease. Additionally, although more and more patient satisfaction/patient reported outcomes are reported, here is also a need for more standardized reporting.

TABLE 4 Aesthetic outcomes.

Author/year	Follow up (mo)	Abutment type	Index	Outcome
Hosseini et al., 2022[a]	60	Titanium vs. Zirconia	Copenhagen Index Score	The six professional-reported aesthetic scores at the 5-year examination were not significantly different between both types of restorations
Baldini et al., 2016	12	Titanium vs. Zirconia	Implant Crown Aesthetic Index	Total: 14 for Zirconia and 9 for titanium. No statistical significant intergroup differences.
			Papilla Index	An improvement was observed after 12 months in both groups, with significant intragroup differences (for the test group, $p=.008$; for the control group, $p=.001$). Intergroup difference NR.
Fenner et al., 2016	60	Titanium vs. Aluminum oxide	Papilla index	No intergroup differences
			Clinical crown length	Clinical crown length showed significantly higher values in the titanium group.
Ferrari et al., 2015	24	Titanium vs. Gold-hue vs. Zirconia	NR	NR
Carrillo de Albornoz et al., 2014	12	Titanium vs. Zirconia	Implant Crown Aesthetic Index	ICAI total: 7.6 for Zirconia and 10.6 for titanium. No statistical significant intergroup differences.
			Papilla index	Tendency to higher interdental papilla score in the test group.
Zembic et al., 2013[b]	60	Titanium vs. Zirconia	Distance from the mucosal/gingival margin to the crown margin/cemento-enamel junction	No significant differences were detected examining the mean distance of the mucosal margin to the crown margin when using zirconia versus titanium abutments.
			Papilla index	No significant difference in the mean papilla height mesial and distal of crowns supported by zirconia or titanium abutments.
Hosseini et al., 2011[a]	12	Titanium vs. Zirconia	Copenhagen Index Score	The overall professional reported aesthetic outcome was not significantly different between both types of restorations after 1 year (AC: mean 9.3, SD 1.9; MC: mean 9.1, SD 1.4; $p=.705$).
Sailer et al., 2009[b]	12	Titanium vs. Zirconia	Difference of color of the peri-implant mucosa and the gingiva of control teeth was evaluated by means of a spectrophotometer (Spectroshade).	Visible difference of the mucosal color compared with natural teeth. But the amount of discoloration was not significantly different between the titanium and the zirconia abutment-borne crowns.
			Soft tissue thickness	No intergroup comparison mentioned.
			Papilla index	No intergroup comparison mentioned.
Zembic et al., 2009[b]	36	Titanium vs. Zirconia	Difference of color of the peri-implant mucosa and the gingiva of control teeth was evaluated by means of a spectrophotometer (Spectroshade).	Visible difference of the mucosal color compared with natural teeth. But the amount of discoloration induced by zirconia and titanium abutments was not significantly different.
			Soft tissue thickness	No difference at zirconia versus titanium abutments.
			Papilla index	No intergroup differences.
Vigolo et al., 2006	60	Titanium vs. Gold-alloy	NR	NR
Andersson et al., 2003	48	Titanium vs. Alumina	NR	The clinicians rated the esthetic result as excellent or good in 92% and acceptable in 8% of the cases at FPD insertion. The results were comparable for ceramic and titanium abutments.

(Continues)

TABLE 4 (Continued)

Author/year	Follow up (mo)	Abutment type	Index	Outcome
Andersson et al., 2001	36	Titanium vs Alumina	NR	At the 1-year follow-up the clinician rated the esthetic result in 100% of the cases as excellent or good in the test group and in 97% of the cases as excellent or good in the control group (and 3% as acceptable).

Abbreviations: Mo, months; NR, not reported; yr, year.
[a]Examining the same patient population.
[b]Examining the same patient population.

TABLE 5 Patient satisfaction.

Author/year	Follow up (mo)	Abutment type	Index	Outcome
Hosseini et al., 2022[a]	60	Titanium vs. Zirconia	Patient-reported aesthetic outcome based on selected questions from the Oral Health Impact Profile questionnaire (OHIP-49)	The patients were also satisfied with both the aesthetic and functional results of the implant-supported single-tooth restorations of both materials.
Baldini et al., 2016	12	Titanium vs. Zirconia	Satisfaction questionnaire concerning items such as the esthetic-related variables	Patient feedback was positive in both test and control groups: the final opinion on esthetic outcomes demonstrated a degree of general satisfaction.
Fenner et al., 2016	60	Titanium vs. Aluminum oxide	Visual analog scale (VAS) to evaluate patient's overall satisfaction (on a scale from 0 to 10)	Patient's satisfaction revealed 9.7 on the visual analog scale.
Ferrari et al., 2015	24	Titanium vs. Gold-hue vs. Zirconia	NR	NR
Carrillo de Albornoz et al., 2014	12	Titanium vs. Zirconia	Visual analog scale (VAS) to evaluate patient's aesthetics satisfaction.	Patient satisfaction was similarly high in both groups (visual analogue scale 8.5).
			Written questionnaire evaluating satisfaction regarding the aesthetic appearance, the phonetic ability, and overall satisfaction with the treatment (six-grade ordinal scale).	The questionnaire demonstrated a good acceptance of the received treatment.
Zembic et al., 2013[b]	60	Titanium vs. Zirconia	NR	NR
Hosseini et al., 2011[a]	12	Titanium vs. Zirconia	Patient reported visual analogue scale (VAS)—a 100 mm line with the end phrases 'Very bad aesthetic' on the left (0 mm) and 'Very good aesthetic' on the right (100 mm)	The patient-reported overall aesthetic evaluations demonstrated no significant difference in the VAS scores between the AC and the MC restorations
Sailer et al., 2009[b]	12	Titanium vs. Zirconia	NR	NR
Zembic et al., 2009[b]	36	Titanium vs. Zirconia	NR	NR
Vigolo et al., 2006	60	Titanium vs. Gold-alloy	NR	NR
Andersson et al., 2003	48	Titanium vs. Alumina	NR	All patients were fully satisfied with the achieved esthetic results at both FPD insertion and the 5-year appointment.
Andersson et al., 2001	36	Titanium vs. Alumina	NR	All patients were fully satisfied with the achieved esthetic results at the 1-year follow-up.

Abbreviations: Mo, months; NR, not reported; yr, year.
[a]Examining the same patient population.
[b]Examining the same patient population.

TABLE 6 Risk of bias assessment according to the Cochrane Risk of Bias 2 tool.

Author/year	Randomization	Deviations from intended intervention	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall risk of bias
Hosseini et al., 2022[a]	Yellow	Green	Green	Green	Green	Yellow
Baldini et al., 2016	Green	Green	Yellow	Green	Green	Yellow
Fenner et al., 2016	Green	Green	Yellow	Green	Green	Yellow
Ferrari et al., 2015	Green	Green	Green	Green	Green	Green
Carrillo de Albornoz et al., 2014	Green	Green	Green	Green	Green	Green
Zembic et al., 2013[b]	Yellow	Green	Yellow	Green	Green	Yellow
Hosseini et al., 2011[a]	Yellow	Green	Green	Green	Green	Yellow
Sailer et al., 2009[b]	Yellow	Green	Yellow	Green	Green	Yellow
Zembic et al., 2009[b]	Yellow	Green	Yellow	Green	Green	Yellow
Vigolo et al., 2006	Yellow	Green	Green	Green	Green	Yellow
Andersson et al., 2003	Yellow	Green	Green	Green	Green	Yellow
Andersson et al., 2001	Yellow	Green	Green	Green	Green	Yellow

Note: Green: low risk of bias; yellow: some concerns for risk of bias; red: high risk of bias.
[a]Examining the same patient population.
[b]Examining the same patient population.

Finally, there is also often a lack of details about the abutment characteristics, such as the macroscopic design and surface roughness, abutment height and emergence angle, although we know that these also influence the surrounding tissues (Laleman & Lambert, 2023; Nothdurft et al., 2015; Quirynen et al., 1996; Teughels et al., 2006; van Brakel et al., 2011). Additionally, details about the implant-abutment interface (e.g. type of connection) are lacking. On the other hand, most studies mention if screw-retained or cemented restorations were used, but in several studies both types are used interchangeably, which made a subanalysis impossible.

A limit of this study is that because of time limitations the search was limited to studies published from January 2000. Due to this time limit, we will most likely not have missed any eligible articles on zirconia abutments, as they were only introduced around this time. However, we are aware that we probably did not include potentially eligible articles on alumina and gold abutments. Another limitation of this study is that transmucosal components clearly consisting of different materials were excluded. This was done because the authors deemed that it impossible to assess the effect of each material individually for transmucosal components existing of two materials. However, this ignores the clinical reality where dental implant are now frequently restored with monolithic restorations bonded on a titanium bases (TiB) of various tranmucosal heights. This type of restoration brings new challenges as, especially in case of short TiB heights, a significant part of the transmucosal tissues is in direct contact with the restorative material such as zirconia, lithium disilicate, hybrid composite, polymer infiltrated composite newtwork (PICN) or even polyetheretherketone (PEEK). Although there are some promising clinical results about abutments made of for example PEEK (Ayyadanveettil et al., 2021), in general this new generation of materials is poorly investigated clinically concerning their effect on the surrounding peri-implant tissues.

5 | CONCLUSIONS

This systematic review shows that based on randomized clinical trials no differences between abutment materials can be found on the surrounding peri-implant tissues.

AUTHOR CONTRIBUTIONS

I. Laleman: Data curation and writing–original draft/review and editing, F. Lambert: supervision and writing–review and editing, M. Gahlert: writing–review and editing, M. Bacevic: conceptualization, H. Woelfler: statistical analysis and visualization, S. Roehling: data curation and writing–original draft/review and editing.

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DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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