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Clinical and radiographic outcomes of zirconia dental implants—A systematic review and meta-analysis

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Abstract

Objectives: For the present review, the following focused question was addressed: In patients with root-analog dental implants, what is the effect of implants made of other materials than titanium (alloy) on implant survival, marginal bone loss (MBL), and technical and biological complications after at least 5 years.

Materials and Methods: An electronic (Medline, Embase, Web of Science) search was performed to identify observational clinical studies published from January 2000 investigating a minimum of 20 commercially available zirconia implants with a mean follow-up of at least 60 months. Primary outcome was implant survival, secondary outcomes included peri-implant MBL, probing depths (PDs), and technical and biological complications. Meta-analyses were performed to evaluate implant survival, MBL, and PD.

Results: From 5129 titles, 580 abstracts were selected, and 111 full-text articles were screened. Finally, 4 prospective and 2 retrospective observational clinical cohort studies were included for data extraction. Meta-analyses estimated after 5 years of loading mean values of 97.2% (95% CI 94.7–99.1) for survival (277 implants, 221 patients), 1.1 mm (95% CI: 0.9–1.3) for MBL (229 implants, 173 patients), and 3.0 mm (95% CI 2.5–3.4) for PDs (231 implants, 175 patients).

Conclusions: After 5 years, commercially available zirconia implants showed reliable clinical performance based on survival rates, MBL, and PD values. However, more well-designed prospective clinical studies and randomized clinical trials investigating titanium and zirconia implants are needed to confirm the presently evaluated promising outcomes.

KEYWORDS

biological complications, dental implants, implant survival, marginal bone loss, meta-analysis, probing depths, technical complications, yttria stabilized tetragonal zirconia, zirconium oxide

1 | INTRODUCTION

For many decades, titanium has been used for the fabrication of dental implants and abutments. In recent years, esthetic outcomes

– especially in the anterior region – have become very important. The dark grayish color of titanium implants and abutments can be a major drawback regarding white and pink esthetics (Glauser et al., 2004; Jung et al. 2008). However, not only the focus on

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esthetics but also the biological awareness of clinicians and patients has changed. Metals like commercially pure titanium or specific titanium–zirconium alloy show very good soft and hard tissue integration capacities and excellent clinical performance (Roehling et al., 2015). However, concerns have been raised regarding the potential of titanium to induce hypersensitivity or inflammatory reactions in the host tissues which could lead to various biological complications. In addition, an association between plaque, biocorrosion, presence of titanium particles, and biological implant complications has been reported (Mombelli et al., 2018).

In clinical studies, alumina and zirconia have been investigated as implant materials other than titanium or titanium–zirconium. Alumina implants were established on the market at the end of the 1960s and were clinically used until the beginning of the 1990s (De Wijs et al., 1994). At the beginning of 2004, zirconia was established on the market as an implant material and is currently the only material that is used for the fabrication of ceramic dental implants with 1- and 2-piece designs. Based on superior biomechanical properties, zirconia implants can withstand oral occlusal forces (Kohal et al., 2015). So far, systematic reviews investigating the clinical performance of zirconia implants estimated mean survival rates between 95% and 97.2% only for follow-up periods of 1 and 2 years (Pieralli et al., 2017; Roehling et al., 2018). However, even though meta-analyses are limited to 1 and 2 years of follow-up, clinical studies investigating zirconia implants after functional loading periods of 5 years and more have most recently been published (Brunello et al., 2022; Gahlert et al., 2022). So far, no systematic reviews and meta-analyses evaluating the clinical and radiographic performance of zirconia implants after follow-up periods of more than 2 years are available.

The intended focused question for this invited review (2023 ITI consensus conference) was: '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, due to the large heterogeneity of the available abutment and implant studies (several randomized controlled clinical trials available investigating abutments, while this is not the case for the commercially available implant materials), it was not possible to combine both topics. Consequently, the focused question was answered in two separate systematic reviews. The present manuscript reports data on implant materials, while information regarding abutment materials will be the subject of another systematic review (Laleman et al.).

For the present systematic review, the focused question to be addressed was as follows:

In patients with root-analog dental implants, what is the effect of implants made of other materials than titanium or a specific titanium alloy on implant survival, marginal bone loss (MBL), and technical and biological complications after at least 5 years?

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 (Scharadt et al., 2007). The protocol for this systematic review was registered on PROSPERO (CRD42022376487).

2.1 | 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 are found in Appendix S1.

Additional hand searches were performed and included the following: bibliographies of previous reviews on the subject and bibliographies of all included full-text articles. Moreover, a manual search of the reference lists of relevant articles published in *Clinical Oral Implants Research*, *International Journal of Oral & Maxillofacial Implants*, *Clinical Implant Dentistry and Related Research*, *Journal of Periodontology*, and *Journal of Clinical Periodontology* was performed.

2.2 | Eligibility criteria

2.2.1 | Implant studies

For the part of the systematic review focusing on the implants, the following inclusion criteria were defined:

- Human, observational trials (prospective and retrospective) investigating implants made of materials other than commercially pure grade 4 titanium or specific titanium alloys published from January 2000.
- Implant types and surface topographies investigated in the included studies have not been removed from the market, respectively, replaced on the market by a further developed, next generation of the same type of implant.
- At least 20 implants were evaluated at follow-up.
- Follow-up for at least 60 months after implant placement.
- Reported details regarding implant survival.
- Reported details regarding peri-implant marginal bone loss.
- Language: English.

Studies not meeting the inclusion criteria were excluded from the review. Moreover, clinical studies investigating individually designed zirconia implants or multiple publications on the same patient population, as well as investigations based on charts, questionnaires, or interviews as well as case reports were excluded. Due to time limitations and invited systematic review, only articles published in the English language could be included in the present manuscript.

2.2.2 | Selection of studies

After the elimination of duplicates, the reviewers (SR, IL) independently screened titles, abstracts, and full texts meeting the selection criteria. For the screening of titles and abstracts, the free web and mobile

app Rayyan (<http://rayyan.qcri.org>) was used (Ouzzani et al., 2016). Unclear titles 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 the title and abstract selection (Landis & Koch, 1977).

2.2.3 | Data extraction and outcome measures

The primary outcome was implant survival. Secondary outcomes included peri-implant MBL, peri-implant probing depths (PDs) as well as technical and biological complications.

Implant survival was defined as the implant remaining in situ for the observation period.

MBL was calculated as the difference between implant placement and the last follow-up examination.

PDs were monitored at the last follow-up examination.

Technical complications were defined as implant or abutment fracture, fracture of the implant prosthesis, chipping of the veneering ceramic, and loosening of the implant prosthesis.

The biological complications included bone loss of more than 2 mm over the observation periods, soft tissue complications (swelling, fistulas, mucositis), and peri-implantitis.

The timing of implant placement was classified as defined by Hammerle et al., 2004:

- Type 1: Immediate implant placement following tooth extraction.
- Type 2: Early implant placement after complete soft tissue healing (4–8 weeks).
- Type 3: Early implant placement after partial bone healing (12–16 weeks).
- Type 4: Late implant placement after complete bone healing (more than 16 weeks).

Implant loading protocols were classified as follows by (Weber et al., 2009):

- Immediate loading: Functional loading of implants earlier than 1 week subsequent to implant placement.
- Early loading: Functional loading of implants between 1 week and 2 months subsequent to implant placement.
- Conventional loading: Functional loading after more than 2 months subsequent to implant placement.

Implant failures were classified as follows:

- Early implant failures: Implant loss before prosthetic loading (Broggini et al., 2007).
- Late implant failures: Implant loss after prosthetic loading (Broggini et al., 2007).
- Implant fractures.

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. In case of missing or unclear information, the corresponding authors of the articles were contacted via email. If the information was still not sufficient for inclusion and evaluation, the study was excluded from the present review.

From the included clinical full-text articles, the following data were extracted: author(s), year of publication, design of study (retrospective study design [RE]/prospective study design [PR]/randomized clinical trial [RCT]), number of included patients and implants, implant material (yttria-stabilized zirconia [YTZP]/alumina-toughened zirconia [ATZ]/titanium), implant design (1-piece/2-piece), implant system, implant surface treatment, surface roughness, market availability of investigated zirconia implant surface (yes/no), type of implant placement (Type 1/2/3/4), use of bone augmentation during surgery (yes/no), use of immediate temporization directly after implant placement (yes/no), immediate loading (yes/no), time period between implant placement and final prosthetic reconstruction (weeks), type of prosthetic restoration on implants and abutments (single crown [SC]/fixed dental partials [FDPs]/removable hybrid dentures [RHDs]), retention modes prosthetics (abutments and prostheses, cement-retained [CR]/screw-retained [SR]), number of drop outs, number of early/late implant failures and implant fractures, mean observation period (months), implant survival (%), and mean peri-implant MBL (mm). Moreover, technical and biological complications as well as PDs were recorded.

2.2.4 | Quality assessment and risk of bias

Two reviewers (IL and SR) independently screen the included cohort studies and assessed for quality and reporting using the Newcastle–Ottawa scale, which includes 8 key domains. One star is awarded for each domain in which the criteria are fulfilled, except for ‘comparability’ which can be awarded two stars.

2.3 | Statistical analysis

For survival rates after 60 months, MBL and mean PD, a random-effect meta-analysis was performed using metaprop and metan in Stata statistical software version 17.0 (StataCorp LLC). The amount of heterogeneity across studies was assessed with the I^2 measure (Higgins et al., 2003). For the survival rates, exact binomial 95% confidence intervals were calculated. Since the survival rates are at 1 in some studies, we enabled the Freeman–Tukey double arcsine transformation to include such studies in the pooled estimate and to guarantee the pooled estimate to be within the [0, 1] interval (Nyaga et al., 2014). For MBL and PD, 95% confidence intervals for means were calculated using standard errors derived from the reported standard deviations.

Forest plots were used for the graphic presentation of survival rates, MBL and mean PD 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, [Figure 1](#)). After the 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 6 clinical studies fulfilled the inclusion criteria and were included in the present qualitative and quantitative analyses ([Figure 1](#), [Tables 1–4](#)). In total, 93 reports had to be excluded ([Table 5](#)). The inter-examiner agreement was $\kappa=0.82$.

3.1 | Study characteristics

The literature search has shown that in clinical studies, only zirconia and alumina have been used as alternative implant materials instead of commercially pure titanium, or a specific titanium alloy. Since alumina implants have been removed from the market in the 1990s, only studies investigating zirconia as an implant material were included in the present review.

Based on the eligibility criteria, only observational studies were included for data extraction and further statistical analysis. Altogether, 6 observational clinical cohort studies with prospective ($n=4$) and retrospective ($n=2$) designs investigating 1-piece (5 studies, 229 implants) and 2-piece zirconia implant designs (1 study,

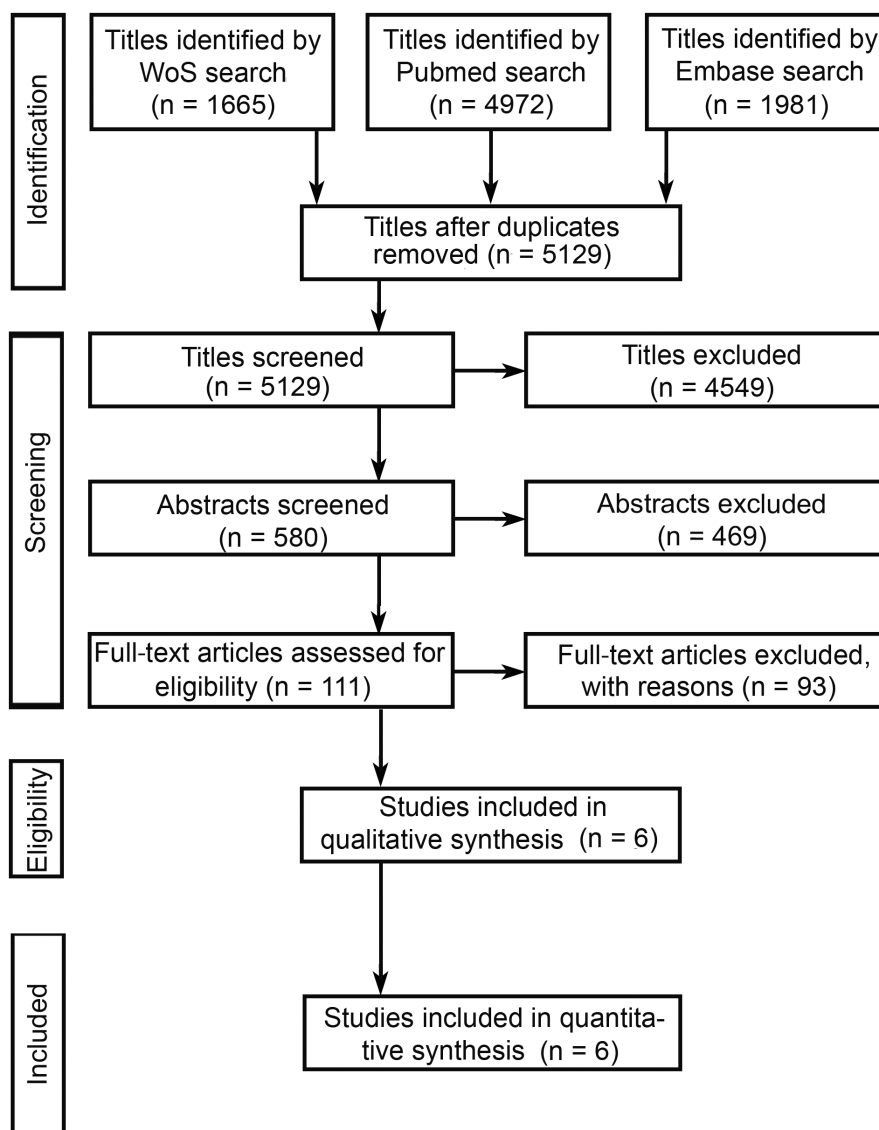


FIGURE 1 Search strategy and selection process for the included studies.

TABLE 1 Characteristics of clinical studies investigating implant survival.

Author/year	Study Design	Patients (n)	Impl. (n)	Impl. Design	Setting	Company/implant type	Surface treatment	Surface roughness (µm)
Brunello et al., 2022	RE	48	48	2	Univ.	Patent, Zircon-Medical, former ZV3, Zirkon Vision GmbH	Air particle abrading, sintering	Ra 7.0
Gahlert et al., 2022	PR	44	44	1	Priv. pract. and Univ.	Straumann/PURE Ceramic Implant	Sandblasting, large-grit and acid etching	Sa 7.0
Borgonovo et al., 2021	RE	12	29	1	Univ.	Bredent/WhiteSky	Sandblasting	Ra 0.9–1.0
Balmer et al., 2020	PR	60	71	1	Univ.	Vita Zahnfabrick/ceramic, implant Vitaclinic	Sandblasting and acid etching	Ra 1.2
Kohal et al., 2020	PR	40	53	1	Univ.	Metoxit AG/Ziraident FR 1	Sandblasting, Sintering with pore-building polymers	Ra 1.8
Grassi et al., 2015	PR	17	32	1	Priv. pract. and Univ.	Bredent/WhiteSky	Sandblasting	Sa 1.17

Abbreviations: 1, 1-piece implant design; 2, 2-piece implant design; ATZ, alumina-toughened zirconia; Impl. Design, Implant Design; Impl, Implants; PR, prospective study design; Priv. pract.: Private practice; RE, retrospective study design; Ti, Titanium; Univ: University; YTZP, yttria-stabilized zirconia; NR, not reported.

48 implants) were included in the analysis ([Balmer et al., 2020; Borgonovo et al., 2021; Brunello et al., 2022; Gahlert et al., 2022; Grassi et al., 2015; Kohal et al., 2020], [Table 1]). The risk of bias assessment of these studies is shown in Table 6. The investigated implant diameters ranged between 3.5 mm and 5.5 mm. Implant placement was performed immediately after tooth extraction (type 1), after soft tissue (type 2) or osseous healing (types 3 and 4). Immediate temporization after implant placement was performed in 4 studies, whereas immediate loading was allowed in only 1 study. All the included investigations allowed simultaneous bone augmentation procedures and the time periods between implant placement and insertion of the final prosthetic reconstruction ranged between 8 and 26 weeks, whereas SCs and FDPs were investigated. All the investigated prosthetic reconstructions – abutments as well as SCs and FDPs – were cement retained. The evaluated implants were either placed in a university setting (4 studies, 199 implants [Balmer et al., 2020; Borgonovo et al., 2021; Brunello et al., 2022; Kohal et al., 2020]) or in a multicenter setting consisting of university and private practice (2 studies, 76 implants [Gahlert et al., 2022; Grassi et al., 2015], Tables 1 and 2).

3.2 | Implant survival

Altogether, data from 277 implants placed in 221 patients were included in the analysis regarding implant survival. The meta-analysis estimated 5-year mean survival rates of 97.1% (CI 91.6–100.0) and 97.3% (CI 94.2–99.3) for retrospective and prospective studies, respectively. Considering all the included studies, the 5-year mean survival rate was 97.2% (CI 94.7–99.1), whereas a low degree of heterogeneity was evaluated for the included studies ($I^2=0.0\%$, $p=.5$, Figure 2).

A total of 38 patients (17.4%) and 40 zirconia implants (14.5%) were reported as dropouts for reported follow-up periods between 60 and 120 months (Table 3). The overall failure rate was 3.8%, whereas 8 implants were classified as early (3.4%) and 1 implant as late failure (0.4%). The reported survival rates ranged between 93.8% and 100% (Table 3). Only 1 study investigated 48 2-piece zirconia implants. After implant placement and unloaded healing of 10–12 weeks, fiberglass abutments as well as single crowns were cemented. After a mean follow-up period of 111.1 months (± 2.2), 32 implants were evaluated, and the authors reported a survival rate of 93.8% (Brunello et al., 2022).

3.3 | Peri-implant MBL

Overall, 229 implants placed in 173 patients were evaluated (Table 3). Regarding prospective studies, the meta-analysis estimated a mean 5-year MBL of 1.0 mm (CI 0.8–1.3). Only 1 retrospectively designed study reported MBL (Borgonovo et al., 2021). Considering all included studies, the evaluated mean 5-year MBL was 1.1 mm (CI 0.9–1.3). A low degree of heterogeneity was found between the studies ($I^2=4.9\%$, $p=.4$, Figure 3).

TABLE 2 Surgical and prosthetic characteristics of included clinical studies.

Author/year	Material	Type implant placement	Simultaneous bone augmentation	Immediate temporization	Immediate loading	Time period placement – Final reconstruction (weeks)	Prosthetics	Retention modes (abutments/prostheses)
Brunello et al., 2022	YTZP	2,3,4	Yes	No	No	Maxilla: 12 Mandible: 10	SC	CR/CR
Gahlert et al., 2022	YTZP	2,3,4	Yes	No	No	26	SC	-/CR
Borgonovo et al., 2021	YTZP	2,3,4	Yes	Yes	No	24	SC/FDP	-/CR; -/CR
Balmer et al., 2020	YTZP	2,3,4	Yes	Yes	No	Maxilla: 16 Mandible: 8	SC/FDP	-/CR; -/CR
Kohal et al., 2020	ATZ	NR	Yes	Yes	No	Maxilla: 16 Mandible: 8	SC/FDP	-/CR; -/CR
Grassi et al., 2015	YTZP	1,4	Yes	Yes	Yes	14	SC	-/CR

Abbreviations: ATZ, alumina-toughened zirconia; CR, cement-retained; FDP, fixed dental partials; RHD, removable hybrid denture; SC, single crowns; SR, screw-retained; Ti, titanium; YTZP, yttria-stabilized zirconia.

TABLE 3 Primary and secondary outcomes of included clinical studies.

Author/year	Impl. (n)	Material	Fol. Up after placement (months)	Drop outs implants (n)	Early failures (n)	Late failures (n)	Fractures (n)	Survival rate (%)	Mean MBL (mm ± SD)	Mean probing Depths (mm ± SD)
Brunello et al., 2022	48	YTZP	111.1	16	2	1	0	93.8	NR	3 ± 0.6
Gahlert et al., 2022	44	YTZP	60	8	1	0	0	97.7	0.99 ± 0.58	NR
Borgonovo et al., 2021	29	YTZP	120	3	0	0	0	100	0.92 ± 0.97	3.26 ± 1.46
Balmer et al., 2020	71	YTZP	60	7	1	0	0	98.4	0.7 ± 0.6	3.3 ± 0.6
Kohal et al., 2020	53	ATZ	60	5	3	0	0	94.3	0.81 ± 0.77	0.64 ± 0.87
Grassi et al., 2015	32	YTZP	61.2	1	1	0	0	96.8	1.23 ± 0.29	0.53 ± 0.47

Abbreviations: ATZ, alumina-toughened zirconia; NR, not reported; SD, standard deviation; Ti, titanium; YTZP, yttria-stabilized zirconia.

TABLE 4 Technical and biological complications of implants.

Author/year	Impl. (n)	Drop outs implants (n)	Decementation (n)	Abutment fracture (n)	Bone loss >2mm (n)	Soft tissue complications (n)	Peri-implantitis (n)
Brunello et al., 2022	48	16	1	6	NR	13	0
Gahlert et al., 2022	44	8	NR	NA	0	0	0
Borgonovo et al., 2021	29	3	NR	NA	0	NR	0
Balmer et al., 2020	71	7	NR	NA	NR	0	1
Kohal et al., 2020	53	5	NR	NA	4	0	0
Grassi et al., 2015	32	1	NR	NA	0	0	0

Abbreviations: NA, not applicable due to 1-piece implant design; NR, not reported.

TABLE 5 Excluded studies.

Reason for exclusion	Number	Studies
Wrong study design	47	Abduo et al. (2021), Amorfini et al. (2018), Asgeirsson et al. (2019), Ayyadanveettill et al. (2021), Bae et al. 2008), Bienz et al. (2021), Borges et al. (2014), Bradley et al. (2021), Canullo (2007), Chen & Pan (2019), Chen et al. (2008), Cionca et al. (2016), de Oliveira Silva et al. (2020), Di Alberti et al. (2013), Duncan et al. (2022), Eisner et al. (2018), Fabbri et al. (2021), Ferrari et al. (2016), Fonseca et al. (2021), Gallucci et al. (2011), Glauser et al. (2004), Hosseini et al. (2013), Kniha et al. (2018a), Laass et al. (2019), Lops et al. (2013), Lops et al. (2015), Lorenz et al. (2019), Nilsson et al. (2017), Nothdurft & Pospiech (2010), Nothdurft (2019), Nothdurft et al. (2014), Olander et al. (2022), Passos et al. (2016), Pol et al. (2020), Rinke et al. (2015), Rohr et al. (2021), Schepke et al. (2017), Spies et al. (2017), Spies et al. (2019), Thoma et al. (2016), Thoma et al. (2018), van Brakel et al. (2012), Vanlioglu et al. (2012), Vanlioglu et al. (2014), Wilson & Blum (2019), Yoon et al. (2019), Zembic et al. (2015)
Follow-up too short	38	Aldebess et al. (2022), Balmer et al. (2018), Balmer et al. (2022), Becker et al. (2017), Borgonovo et al. (2010), Borgonovo et al. (2011), Borgonovo et al. (2012), Borgonovo et al. (2013), Borgonovo et al. (2015), Bormann et al. (2018), Brandenburg et al. (2017), Brüll et al. (2014), Cannizzaro et al. (2010), Cionca et al. (2015), Gahlert et al. (2013), Gahlert et al. (2016), Gargallo-Albiol et al. (2022), Hagi (2021), Holländer et al. (2016), Jung et al. (2016), Kniha et al. (2018b), Kohal et al. (2013), Kohal et al. (2018), Kohal et al. (2012), Kunavisarut et al. (2020), Oliva et al. (2007), Osman & Ma (2014), Osman et al. (2014), Payer et al. (2013), Payer et al. (2015), Rodriguez et al. (2018), Ruiz Henao et al. (2021), Rutkowski et al. (2022), Siddiqi et al. (2015), Spies et al. (2015), Spies et al. (2016a), Spies et al. (2016b), Vilor-Fernández et al. (2021)
Too few patients	2	Bittencourt et al. (2021), Steyer et al. (2021)
Investigated zirconia implants not commercially available	3	Cionca et al. (2021), Koller et al. (2020), Roehling et al. (2016)
Data not clear for evaluation	1	Oliva et al. (2010)
Not English	1	Li et al. (2017)

One study did not provide any information regarding MBL (Brunello et al., 2022), 5 studies used periapical radiographs to determine MBL between implant placement and the last follow-up investigation (Balmer et al., 2020; Borgonovo et al., 2021; Gahlert et al., 2022; Grassi et al., 2015; Kohal et al., 2020).

3.4 | Probing depths

Altogether, 231 implants placed in 175 patients were evaluated, whereas the PD values ranged between 2.2mm 3.3mm for follow-up periods between 60 and 120months (Table 3).

The meta-analysis estimated 5-year mean PD values of 3.0mm (CI 2.6–3.5) and 2.9mm (CI 2.2–3.7) for retrospective and

prospective studies, respectively. Regarding all included studies, the mean 5-year mean PD value was 3.0mm (CI 2.5–3.4), whereas a substantial degree of heterogeneity was evaluated for the included studies ($I^2 = 69.4\%$, $p = .0$, Figure 4).

One prospective study provided information regarding the presence and incidence of bleeding. However, no information was reported regarding PD (Gahlert et al., 2022).

3.5 | Biological complications

All the included studies provided data regarding biological complications. Of the 277 initially placed implants, information was available for 235 implants at the time point of the last clinical and

TABLE 6 Quality assessment and risk of bias of included observational cohort studies.

Author/year	Representative of the exposed cohort	Selection of the non-exposed cohort	Ascertainment of exposure	Outcome of interest not present at commencement of study	Comparability of cases and controls (maximum 2 stars)	Assessment of outcome	Sufficient follow-up time for outcomes to occur	Adequacy of follow-up	Total
Brunello et al., 2022	*	*	*	*	*	*	*	*	6
Gahlert et al., 2022	*	*	*	*	*	*	*	*	8
Borgonovo et al., 2021	*	*	*	*	*	*	*	*	7
Balmer et al., 2020	*	*	*	*	*	*	*	*	8
Kohal et al., 2020	*	*	*	*	*	*	*	*	8
Grassi et al., 2015	*	*	*	*	*	*	*	*	8

radiographic investigation (range between 60 and 120 months). Two studies reported on peri-implant infections around zirconia implants (Table 4). Brunello and coworkers investigated a patient population that received 48 2-piece zirconia implants. After a follow-up period of 9 years, information was available for 29 implants. The authors reported that before the 2-year follow-up, 10 implants were diagnosed with peri-implantitis and peri-implant mucositis, respectively. After appropriate treatment, these infections could be successfully treated and no further cases of peri-implantitis could be observed until the last follow-up. However, at the 9-year follow-up, signs of inflammation (bleeding on probing) were observed around 13 implants (Brunello et al., 2022). In another study, peri-implantitis was diagnosed around 1 out of 71 initially placed 1-piece zirconia implants after 5 years of investigation, whereas the implant was included in a cumulative therapy, starting with non-surgical procedures (Balmer et al., 2020). Only 1 study reported MBL of more than 2 mm around 4 out of 53 initially placed implants; however, none of the implants lost more than 3 mm of bone. Interestingly, the authors also evaluated some bone gain after 5 years of investigation around 5 implants (Kohal et al., 2020). Regarding biological complications that were present at the last follow-up, the overall complication rate was 7.7%, whereas the incidences for soft tissue complications, bone loss of more than 2 mm, and peri-implantitis were 5.5%, 1.7% and 0.4%, respectively (Table 4).

3.6 | Technical complications

Only 1 study investigating 48 2-piece zirconia implants provided information regarding technical complications (Table 4). After a mean observation period of 43.7 months, the authors reported the documentation of 1 fiberglass abutment and 1 crown fracture followed by the loosening of the new crown. In addition, 6 fractures of the fiber-glass abutment were registered after a mean observation time of 53.7 months, whereas all fractured abutments could successfully be replaced by new ones (Brunello et al., 2022).

Regarding implant fractures, information was available for 235 implants. Considering all included studies, no zirconia implant fractures were reported (Table 3).

4 | DISCUSSION

In the present systematic review, implant materials other than commercially pure titanium or a specific titanium alloy were evaluated. With regards to zirconia implants, the meta-analysis estimated similar survival rates, MBL and PD values after 5 years compared with published data on titanium implants. Although technical complications regarding implant components were similar, the biological complications showed a minor occurrence of zirconia compared with reported data for titanium as implant material.

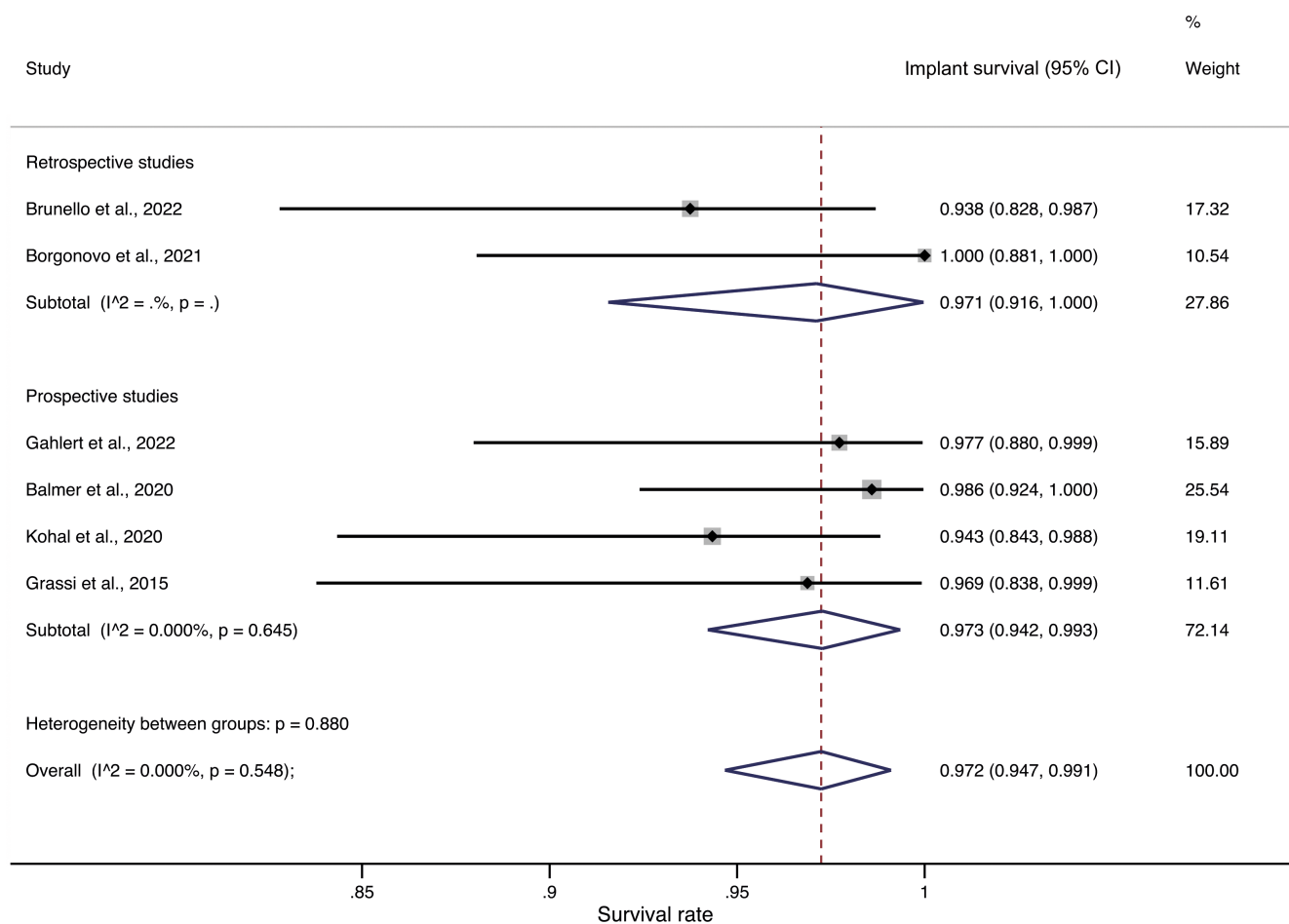


FIGURE 2 Forest plot of 5-year survival rate of implants. ATZ, alumina-toughened zirconia; CI, confidence intervals; YTZP, yttria-stabilized zirconia. Calculations were performed according to the data presented in [Table 3](#).

At the beginning of 2004, the first zirconia implants were established on the market. Consequently, only studies published after 2000 were selected for data extraction in the present review.

Based on many further developments in implant designs and manufacturing processes within the last 2 decades, it has become difficult to interpret published data on zirconia implants and to evaluate the clinical relevance of the investigated implant type and the reported results. This fact must be considered since even the most recently published clinical studies investigate zirconia implants that have been removed from the market many years ago (Cionca et al., 2021; Koller et al., 2020; Lorenz et al., 2019). From a scientific point of view, the reported data are important and well presented; however, the clinical relevance is rather controversial. A meta-analysis has confirmed that physical properties and ongoing market availability significantly influenced the reported zirconia implant survival rates. In a systematic review, clinical studies investigating zirconia implants that were published between 2004 and 2017 were evaluated. The reported 1-year mean survival rates for commercially available zirconia implants (98.3%) were significantly higher compared with zirconia implants that are not any longer commercially available on the market (91.2%). In addition, a mean 2-year survival rate for commercially available zirconia implants of

97.2% was evaluated. This analysis has clearly shown that zirconia implant survival rates have significantly increased between 2004 and 2017 and that the fracture incidence of zirconia oral implants was significantly reduced from 3.4% to 0.2% (Roehling et al., 2018). Consequently, the ongoing market clinical availability of the investigated zirconia implants was considered an important inclusion criterion for the present review.

For example, Cionca and coworkers investigated 39 2-piece zirconia implants after a follow-up period of 6 years. However, the evaluated implant type was removed from the market already in 2013 and has been replaced by a further developed generation of implant type in the meantime (Cionca et al., 2021). Thus, this investigation was not considered for data extraction and further analysis.

Since previously published systematic reviews investigating the clinical performance of zirconia implants already estimated mean survival rates and marginal bone level changes up to 2.75 years (Afrashtehfar & Del Fabbro, 2020; Borges et al., 2020; Elnayef et al., 2017; Haro Adánez et al., 2018; Hashim et al., 2016; Pieralli et al., 2017; Roehling et al., 2018), only clinical studies investigating zirconia implants for a minimum of 5 years were included in the present review.

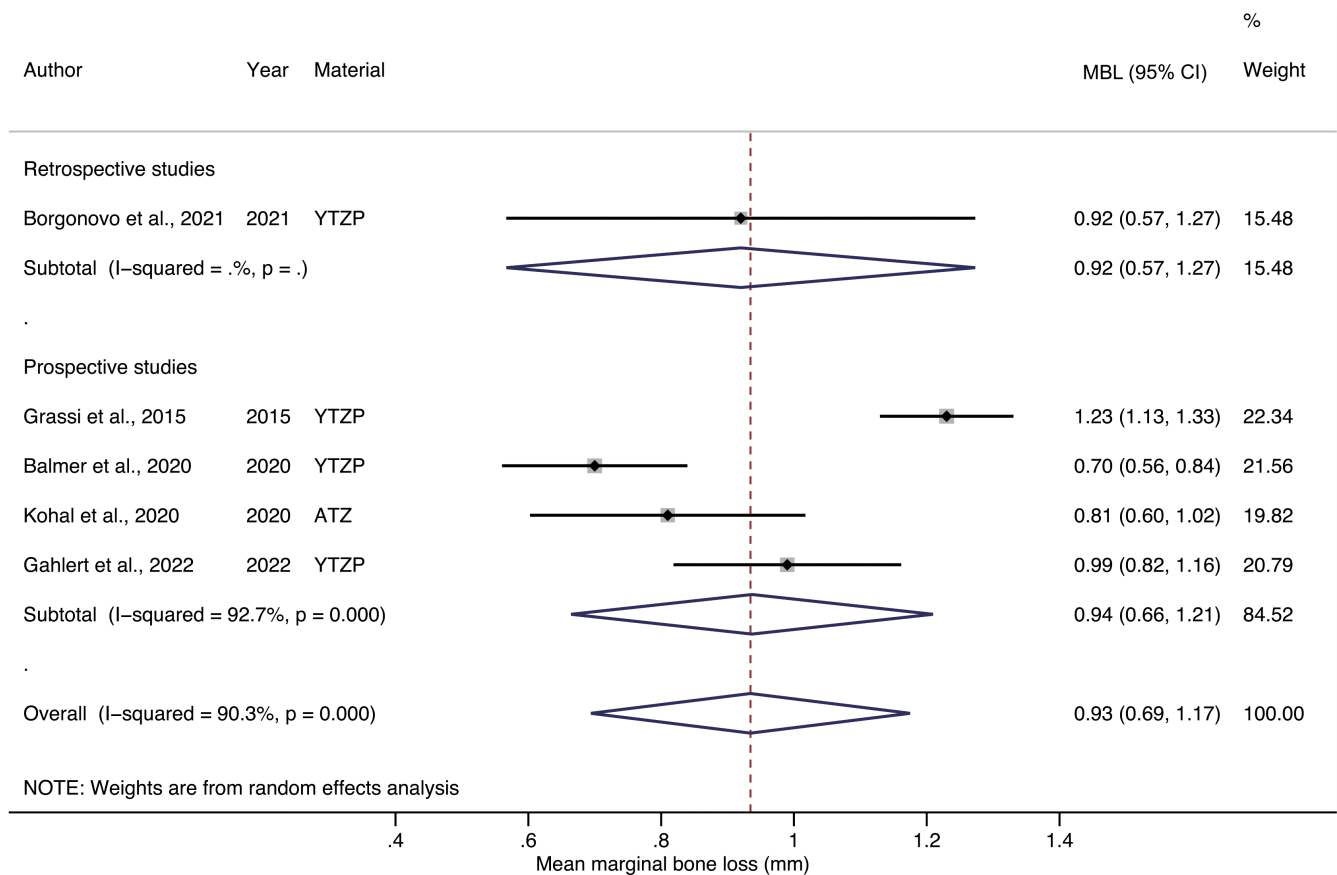


FIGURE 3 Forest plot of 5-year marginal bone loss of implants. ATZ, alumina-toughened zirconia; CI, confidence intervals; MBL, marginal bone loss; YTZP, yttria-stabilized zirconia. Calculations were performed according to the data presented in Table 3.

Implant survival was evaluated as the primary outcome. The meta-analysis has estimated a mean survival rate after 5 years of 97.2% (CI 94.7–99.1). This value is similar to previously published systematic reviews investigating titanium implants after 5 years of functional loading. The authors evaluated mean survival rates between 95.6% and 97.2%, early failure rates between 1.3% and 2.4% and late failure rates between 1.5% and 2.7% for SCs and FDPs (Jung et al., 2012; Jung, Pjetursson, et al., 2008; Pjetursson et al., 2012).

MBL and PD as secondary outcomes were also evaluated using meta-analyses. Regarding MBL, the estimated mean MBL after 5 years was 1.1 mm (CI 0.9–1.3). The evaluated data are in accordance with previously published data for zirconia implants after 1 and 2 years of investigation (Borges et al., 2020; Roehling et al., 2018) and similar to data investigating titanium implants after 5 years of follow-up (Aglietta et al., 2009; Karl & Albrektsson, 2017).

Regarding PD, a mean value of 3.0 mm (CI 2.5–3.4) was estimated. Again, the values are similar to previous data investigating titanium implants after follow-up periods of 5 years (range between 2.7 and 3.6 mm [Hosseini et al., 2022; Zembic et al., 2013]).

Considering technical complications, only 1 study provided information regarding 2-piece zirconia implants with cement-retained abutments and SCs and 1 investigation reported on technical complications of SCs cemented on 1-piece zirconia implants (Brunello et al., 2022). In addition, Spies and coworkers investigated the same

patient population as Balmer and coworkers and reported data on technical complications regarding the prosthetic suprastructures after a mean follow-up period of 61 (± 1.4) months. However, of the 71 placed implants (49 SCs and 22 FDPs), only information was provided regarding 44 SCs placed in molar areas. The authors reported that chipping of the cemented crowns could be observed in 19 patients. Consequently, the authors questioned the concept of bilayered zirconia-based reconstructions and concluded ‘...monolithic approaches might be preferable to overcome this issue...’ (Balmer et al., 2020; Spies et al., 2019). Moreover, the posterior location of the implants and crowns might also have influenced the high-chipping incidence, since in clinical studies, it has been shown that a single crown location had a significant impact on the occurrence of veneer fractures in favor of reconstructions located in the anterior region (Rabel et al., 2018).

The evaluated incidence of soft tissue complications and bone loss of more than 2 mm were 5.5% and 1.7% at the time point of the last follow-up investigation. The values for soft tissue complications are inferior to data on titanium implants reporting values between 7.1% and 8.5% for soft tissue complications and between 5.2% and 2.6% for bone loss of more than 2 mm after 5 years of investigation (Jung et al., 2012; Pjetursson et al., 2012). However, in the latter studies, more implants were evaluated. Regarding peri-implantitis, a low incidence of 0.4% for investigation periods

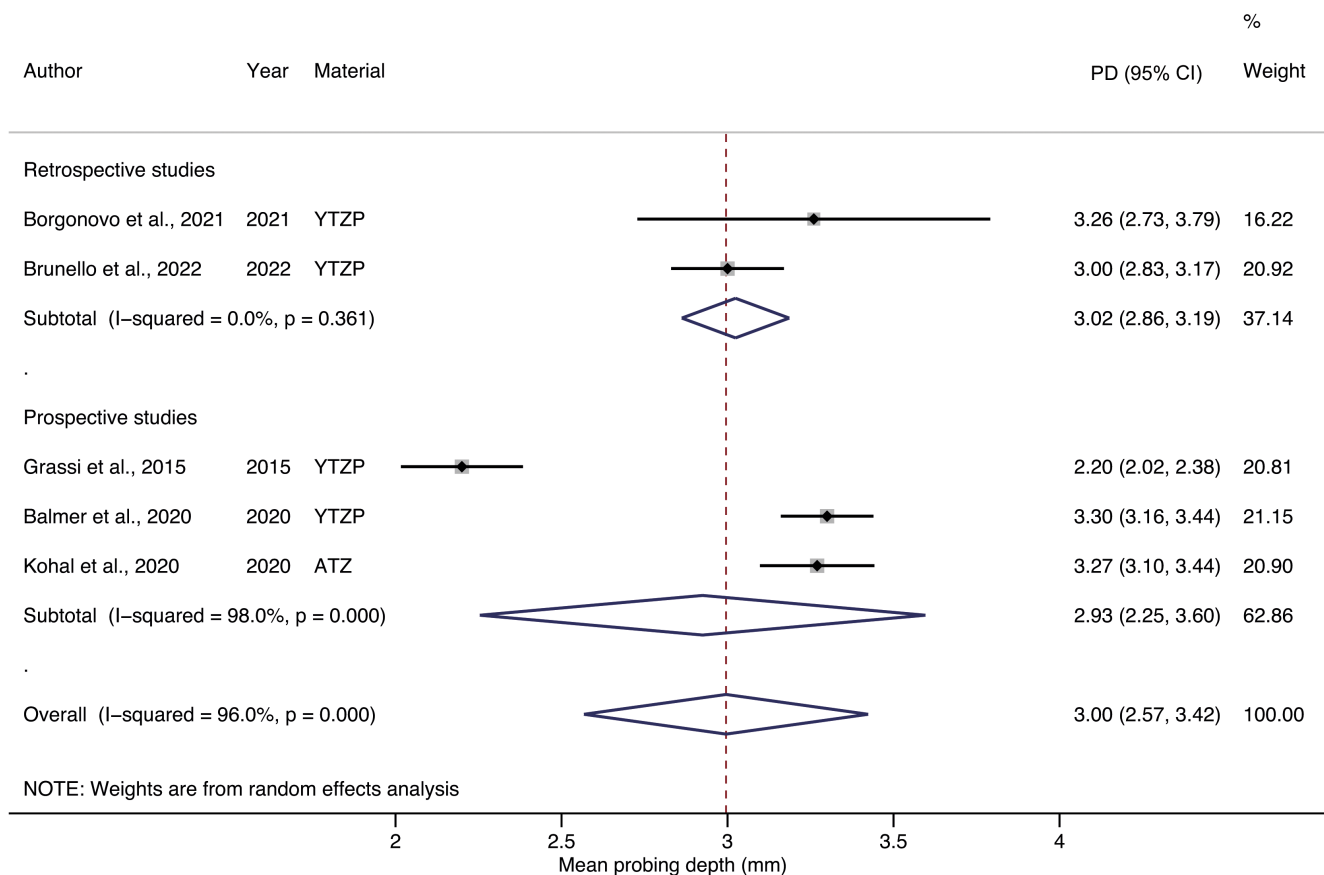


FIGURE 4 Forest plot of probing depth values for implants after 5 years. ATZ, alumina-toughened zirconia; CI, confidence intervals; PD, probing depths; YTZP, yttria-stabilized zirconia. Calculations were performed according to the data presented in [Table 3](#).

between 60 and 120 months was evaluated. For titanium implants, incidences of 43% and 22% were evaluated for peri-implant mucositis and peri-implantitis, respectively, whereas a statistically significant positive relationship between the prevalence of peri-implantitis and mean function time were reported (Derks & Tomasi, 2015). In another study, 4591 titanium implants were investigated. The authors reported that the prevalence of peri-implantitis was between 3.6% and 4.7% after 6 to 7 years of follow-up (French et al., 2019). The presently evaluated peri-implantitis incidence for zirconia implants is inferior compared with the data reported in the latter studies. However, it must be considered that in the present review only information for 235 implants was available.

A limitation of the present review is the low number of zirconia implants ($n=277$) that were evaluated in the meta-analysis for implant survival. In contrast, systematic reviews investigating titanium implants after 5 years of loading included more than 3223 implants (Jung et al., 2012; Pjetursson et al., 2012). Moreover, only observational studies and no randomized clinical trials were considered in the present review. However, based on the current literature search, 6 RCTs are available, comparing titanium and zirconia implants (Koller et al., 2020; Osman et al., 2014; Payer et al., 2015; Ruiz Henao et al., 2021), immediately and conventionally loaded zirconia implants (Cannizzaro et al., 2010) or porcelain-fused-to-metal

and indirect-composite-resin fixed dental prosthetics on zirconia implants (Aldebes et al., 2022). However, 4 studies investigated zirconia implants that are not commercially available, respectively, were removed from the market (Cannizzaro et al., 2010; Koller et al., 2020; Osman et al., 2014; Payer et al., 2015), investigated the same patient population (Koller et al., 2020; Payer et al., 2015) and/or used a novel, unestablished surgical protocol combining alveolar and palatal implants in the maxilla (Osman et al., 2014) or evaluated individually designed, custom-made zirconia implants (Aldebes et al., 2022). Only 1 RCT investigated 16 currently marketed available zirconia implants in comparison to 14 titanium implants. After a follow-up period of 12 months, survival rates of 100% for both types of implants and a mean MBL of 2.08 mm (± 0.55) and 1.96 mm (± 0.48) for zirconia and titanium implants, respectively, were reported (Ruiz Henao et al., 2021).

Based on the low number of included studies, it was not reasonable to perform further statistical methods like meta-regressions to analyze associations between implant survival, MBL as well as PD and study characteristics like type of implant placement, immediate loading, prosthetics, zirconia implant material, and implant design (1-piece compared with 2-piece). In addition, the included studies did not provide detailed data to evaluate the impact of implant location (anterior or posterior) or implant diameter on the reported primary and secondary outcomes. Previously, it has been reported that

implant diameter and implant location influenced technical complications like zirconia implant fractures. The authors of the latter study investigated 170 zirconia implants with an average in situ period of 36.8 ± 5.3 months. They reported 13 implant fractures, whereas all implants were placed in anterior sites and 12 implants had a reduced diameter of 3.25 mm. The authors related the high-fracture rate to notches and scratches created by an uncontrolled manufacture process. However, it must be noted that the investigated fractured zirconia implants have been removed from the market already in 2006 (Gahlert et al., 2012).

5 | CONCLUSIONS

Regarding zirconia implants, the present meta-analyses estimated 5-year mean values of 97.2% (95% CI: 94.7–99.1%), 1.1 mm (95% CI: 0.9–1.3 mm), and 3.0 mm (95% CI: 2.5–3.4 mm) for implant survival, peri-implant MBL and PDs, respectively. Thus, commercially available zirconia implants are a reliable treatment option for follow-up period up to 5 years. Further prospectively designed clinical long-term studies and randomized clinical trials investigating titanium and zirconia implants are needed to confirm the presently evaluated promising outcomes.

AUTHOR CONTRIBUTIONS

S. Roehling: Data curation; Writing – original draft; Writing – review & editing. M. Gahlert: Supervision; Writing – review & editing. M. Bacevic: Conceptualization. H. Woelfler: Statistical Analysis; Visualization. I. Laleman: Data curation; Writing – original draft; Writing – review & editing.

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CONFLICT OF INTEREST STATEMENT

The authors report no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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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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