Zirconia Implants as an Alternative to Titanium: A Systematic Review and Meta-Analysis

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Purpose: *The aim of the present study was to systematically evaluate the marginal bone loss (MBL), success, and survival of zirconia (Zi) implants and compare them with the widely studied titanium (Ti) implants.* ***Materials and Methods:*** *An electronic and manual literature search of several databases was performed by two independent reviewers for articles up to July 2015 that reported the use of Zi implants and survival, success, and MBL with at least 12 months' follow-up. In addition, random effects meta-analyses of selected studies were applied to analyze the weighted mean difference of survival, success, and MBL between groups. Meta-regression analysis was conducted to investigate any potential influence of confounding factors.* ***Results:*** *Twenty-one articles were included, analyzing a total of 1,948 Zi implants with a survival rate of 91.5% and a success rate of 91.6% for 1,250 Zi implants. In addition, three studies were included in the quantitative synthesis and were meta-analyzed for the comparison of survival between Zi and Ti implants, with Zi implants having an 89% greater risk of failure compared with Ti implants (OR = 1.89). There were no statistically significant differences (P = .968) in the success of Zi and Ti implants (odds ratio [OR] = 1.02; 95% confidence interval [CI], 0.47–2.20). MBL (± SD) for Zi implants was 0.89 ± 0.18 mm, which was greater than the MBL for Ti implants (mean difference = 0.14 mm). Also, survival of Zi implants (91.5%) was significantly lower than that of Ti implants (OR = 1.89). Metaregression analysis revealed a similar survival rate for one-piece versus two-piece implants. Similarly, no significant differences were found between immediate and delayed loading.* ***Conclusions:*** *The survival rate of Zi implants was significantly lower than that for the commonly used Ti implants. However, for certain clinical conditions, such as a thin tissue biotype or in the highly esthetic anterior area, Zi implants may offer some benefit when compared with Ti implants.*
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In dentistry, titanium (Ti) has been the material of choice for dental implants since Brånemark defined osseointegration in 1977 as the "direct structural and functional connection between the vital bone and the implant surface."[1] Ti has different degrees of purity (grades I to IV); however, grade IV Ti currently is the most commonly used material because of its strength and biocompatibility.[2] Alloys composed of Ti/aluminum (Ti-6Al-4V) with or without vanadium (Ti-6Al-7Nb) have also been used for dental implants[3] because of their high strength, biocompatibility, and resistance to corrosion.[4,5] Furthermore, Ti implants have demonstrated survival and success rates of 99.4% and 98.8%, respectively, with an observation period of at least 5 years.[6–8] For these reasons, Ti has been widely used and studied in dental implantology.

However, Ti implants are not exempt from weakness or other limitations. First, if visible in the oral cavity, this material may represent an esthetic complication, especially when used in the anterior area. Second, although the effect and implications have not been thoroughly investigated, Ti particles stripping off from the implant surface have been found in both soft and hard tissues surrounding these fixtures,[9,10] as well as in the regional lymph nodes.[11] In addition, researchers have described immunologic responses to Ti oxide, which may lead to biologic complications.[12–14] Similarly, Sicilia et al[15] reported a 0.6% prevalence of Ti allergies in more than 1,500 patients. Consequently, because of the abovementioned limitations and potential complications, alternatives to Ti implants have been developed.

Zirconium dioxide (ZrO_2)—or zirconia—has been suggested as an alternative material to Ti to overcome the potential drawbacks of Ti implants. This is especially true in areas of thin tissue biotypes where no metal color should be seen through the tissue.[16,17] Furthermore, the biocompatibility of zirconia (Zi) implants is similar to that of conventional Ti implants, while the former results in less plaque accumulation.[18–21] In addition, Zi implants have demonstrated survival rates ranging from 74% to 98% after 12 to 56 months and success rates ranging from 79.6% to 91.6% after 6 to 12 months.[3]

Surface characteristics of implants are one of the main parameters proven to influence the osseointegration process.[22,23] Recent preclinical studies have shown that, similar to what occurs with Ti implants, both bone-to-implant contact (BIC) and removal torque increase in ceramic-based implants when their surfaces have been treated by means of sandblasting.[24–28]

To date, multiple Zi-based dental implant systems have been marketed without enough evidence to support their use.[29–31] Recent systematic reviews comparing Zi implants with Ti implants found no statistically significant differences in terms of BIC and removal torque; however, included studies were based only on animal models.[21,32] To the best of the present authors' knowledge, only one study has systematically analyzed the literature and provided limited evidence from human studies.[17] Most of the articles included in the study were published before 2000; the authors concluded that Zi implants were not an alternative to Ti implants. However, technologic advancements have resulted in an improved surface treatment for Zi implants, and their survival and success rates have improved.[17,33,34] Hence, the objective of the present systematic review is to analyze and compare the survival, success, and marginal bone loss (MBL) of improved Zi implants with those of traditional Ti implants.

MATERIALS AND METHODS

Information Sources

Two independent reviewers (B.E. and A.L.) conducted a manual and electronic literature search of several databases, including MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials, and Cochrane Oral Health Group Trials Register for articles written in English up to July 2015.

The four parts of the question to be asked are patient, intervention, comparison, and outcome (PICO):

- P: Partial or completely edentulous healthy patients receiving one or more dental implants;
- I: Implant rehabilitation by means of Zi and/or Ti alloy dental implant placement to support prosthetic rehabilitation with a minimum follow-up of 12-months;
- C: The influence of Ti and Zi surfaces and other variables, if any, on implant success and survival and MBL;
- O: Primary outcomes are implant survival and success rates; secondary outcomes are MBL and the influence of other possible confounding factors on implant survival and success rates.

Screening Process

Three major electronic databases were screened. For the PubMed library, combinations of controlled terms (MeSH and EMTREE) and keywords were used whenever possible. In the search terms used, "[mh]" represented the MeSH terms and "[tiab]" represented the title and/or abstract. Other terms not indexed as MeSH and filters also were applied. As such, the key terms used were ((((((((edentulous jaw[MeSH terms]) OR jaw, edentulous, partially[MeSH terms]) OR edentulous mouth[MeSH terms]) AND dental implantation, endosseous[MeSH terms]) OR dental implant[MeSH terms]) OR dental implantation, endosseous[MeSH terms]) AND zirconium[MeSH terms]) OR zirconia[all terms] Filters: Clinical Trial; Humans; English.

In addition, a manual search of periodontics- and implant-related journals was performed to ensure a thorough screening process. Included journals in the manual search were *Journal of Prosthetic Dentistry, Journal of Dental Research, Journal of Clinical Periodontology, Journal of Periodontology, The International Journal of Periodontics & Restorative Dentistry,* and *Clinical Oral Implant Research* from January 2014 to July 2015. References of included and excluded articles also were screened to identify any additional studies.

Eligibility Criteria

The screening process had to be broad because of the dearth of studies with proper randomization and prospective evaluations. Articles were included in this systematic review if they met the following inclusion criteria. Prospective or retrospective studies, with or without randomization, cohort, and case series involving only human subjects for whom clinical outcomes of survival and/or success rates for Zi implants were reported. Accordingly, several factors, such as study design, number of patients included at the last follow-up, number of Zi implants and Ti implants, smoking and/or other systemic conditions that might alter the outcome, type of procedure (immediate early or delayed placement), and type of prosthesis, were recorded and extracted from the selected studies for further evaluation. On the other hand, case reports or case series with fewer than 10 subjects, systematic reviews, preclinical animal studies, human trials not based on Zi implants or any alloy involving Zi or sapphire implants, and in vitro studies were excluded.

Data Analysis

The researchers used R 3.0.2 software for the meta-analysis (R Foundation for Statistical Computing, Institute for Statistics and Mathematics). Two primary outcomes (implant survival and implant success) and one secondary outcome (MBL) were studied. In addition, an evaluation of possible confounding variables was also conducted: these included immediate loading versus delayed loading and one- or two-piece dental implants. Outcomes assessed were implant survival, implant success, and MBL (expressed in millimeters) at the final evaluation for each study. Meta-analysis consisted of an estimation of the proportion of survival, success, and final weighted mean MBL of the included studies through a random-effects model. Meta-regression analysis was also performed to evaluate the potential impact of confounding factors, including type of connection (one piece vs two pieces) and loading protocol (immediate vs delayed), through a random-effects model. The analysis provides global estimates of main outcomes and elucidates whether differences exist. Calculations for both the meta-analysis and meta-regression were based on the inverse variance method of DerSimonian and Laird. For meta-analysis, survival and success were considered a measure of effect odds ratio (OR). Estimates were obtained for a random effects model. For the solution of the meta-analysis, OR estimates are accompanied by 95% confidence intervals and the *P* value of the null effect of the type of implant factor (OR = 1). Graphical representation is made by means of a forest plot for OR and for the natural logarithm of the OR (making estimates symmetrical around 0 and favoring the adjustment to the normal). For analysis of MBL (continuous variable), the weighted mean difference was used as a measure of overall size effect. The significance level used in the analysis is 5% ($\alpha = .05$). MBL was analyzed as a subject unit, and implant success and survival rates were analyzed as an implant unit.

Study of Heterogeneity and Publication Bias

This study addresses heterogeneity by calculating the I^2 statistic (percentage of variability of the estimated effect that can be attributed to heterogeneity of the real effects) and conducting the corresponding statistical test of nullity. Galbraith graphs display the degree of heterogeneity. High heterogeneity was detected among included studies, and a sensitivity test was conducted to study its source. To analyze the risk of bias, funnel plots were made and an Egger test was conducted. The level of significance was set at 5% ($P = .05$).

Quality Assessment

Two reviewers (B.E. and A.L.) designed and assessed the proposal for the present project to make sure the STROBE statement (Strengthening the Reporting of Observational studies in Epidemiology) and PRISMA guidelines were followed to avoid risk of bias and provide a high level of evidence. The STROBE statement consists of a 22-item checklist that should be fulfilled in a systematic review. PRISMA consists of a 27-item checklist and a four-phase flow diagram.[35] The authors used the Newcastle-Ottawa Scale (NOS) to assess the risk of bias in nonrandomized studies. Cohen's kappa coefficient was used to assess interrater agreement. The authors used the randomized clinical trial checklist of the Cochrane Center and the CONSORT (Consolidated Standards of Reporting Trials) to evaluate the quality of randomized controlled trials (RCTs).

RESULTS

Study Selection

An initial search resulted in a total of 175 articles, 58 of which were selected after an evaluation of titles and abstracts. In addition, 18 articles were found through manual searching. The full text of these articles was obtained and thoroughly evaluated. Of these articles, 21 fulfilled the inclusion criteria.[18,29–31,36–52] Accordingly, they were analyzed for each group. For quantitative analysis,[29,48,51] 3 articles were meta-analyzed for implant survival and 2 for implant success[29,51] and MBL[29,48] (Fig 1). Excluded articles are summarized in Table 1.

Characteristics of Included Articles

After the screening process, 21 articles were included in the qualitative study (Table 2). Eighteen of these articles[18,30,31,36–47,49,50,51] were excluded from the quantitative study because they did not compare Zi implants with Ti implants. Therefore, only 3 studies could be meta-analyzed to obtain the success and survival rates, as well as MBL. All implants in the RCTs had been placed in a delayed approach except for those in the study by Cannizaro et al.[41] In this investigation, authors included an equal number of implants placed immediately postextraction as well as delayed. Two studies were based on one-piece Zi implants, while the study

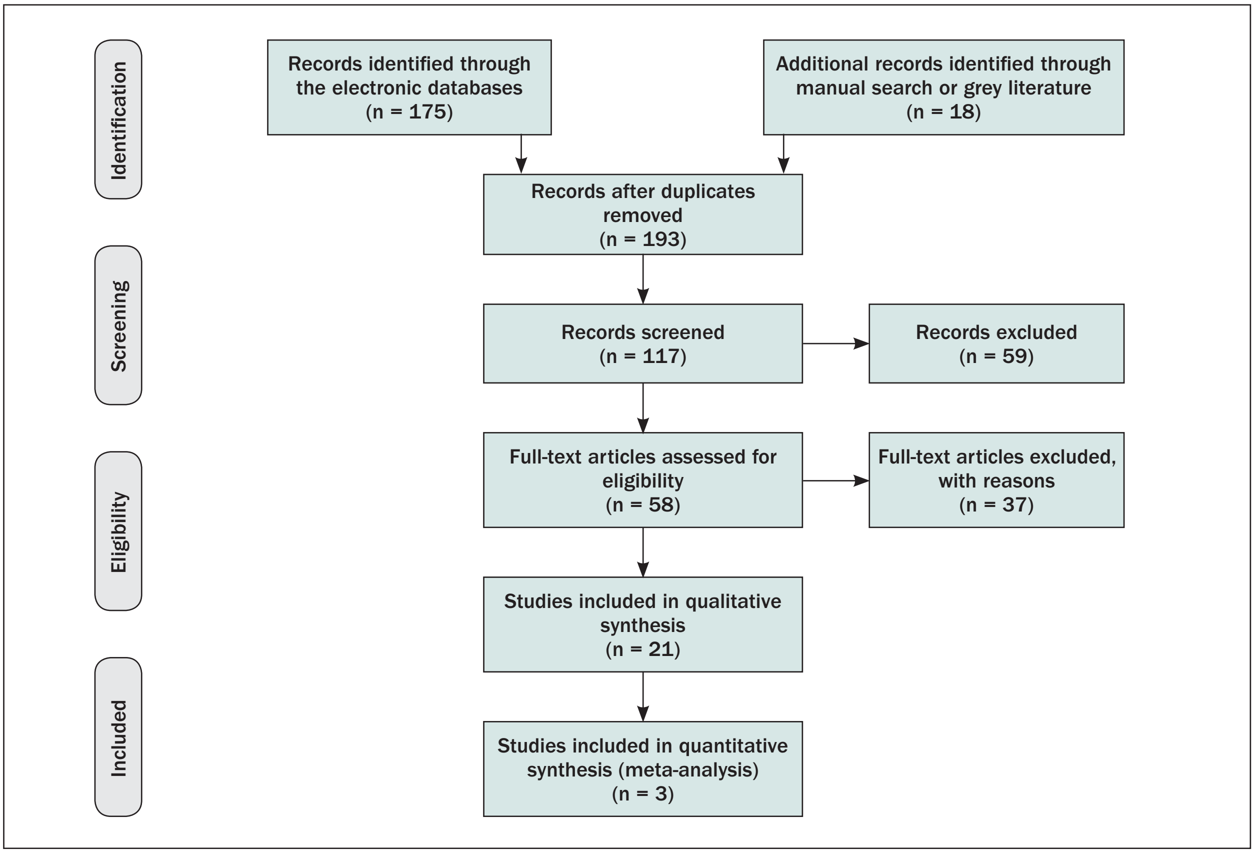

Fig 1 PRISMA flowchart of the screening process.

Table 1 Excluded Articles

Type of Article Excluded	Article
Case report or case series with < 10 patients	Borgonovo et al (2013), Güngor et al (2014), Oliva et al (2008), Borgonovo et al (2012)
Systematic reviews	Andreiotelli et al (2009), Vohra et al (2015)
Preclinical animal studies	Kohal et al (2004), Calvo-Guirado et al (2013), Stadlinger et al (2010), Tetè et al (2009), Bormann et al (2011), Calvo-Guirado et al (2014), Delgado-Ruiz et al (2014), Depprich et al (2008), Gahlert et al (2007), Gahlert et al (2009), Gahlert et al (2010), Gredes et al (2014), Hoffmann et al (2012), Koch et al (2010), Möller et al (2012)
Human trials not studying Zi implants, an alloy of Ti and Zi, or sapphire implants	Berge and Grønningsæter (2000), Müller et al (2015), Karl et al (2104), Quirynen et al (2015), Al-Nawas et al (2012), Al-Nawas et al (2015), Chiapasco et al (2012), Barter et al (2012)
In vitro studies	Delgado-Ruiz et al (2014), Kohal et al (2010), Fischet et al (2015), Nelson et al (2007), Pelaez-Vargas et al (2011), Sanon et al (2015), Delgado-Ruiz et al (2010), Gahlert et al (2011)

by Payer et al[29] was based only on two-piece implants. Also, researchers in two studies restored single-unit implants, while Osman et al[48] rehabilitated completely edentulous patients. There were no restrictions regarding whether implants were placed in the maxilla or mandible in any of the studies. Pirker and Kocher[49] reported greater deviation in the control group compared with the other included studies. In addition, the Zi implants differed from the conventional fixture, so this study was excluded from analysis.

Results of Meta-Analysis for Success, Survival, and MBL

Three studies provided survival data and were included in the meta-analysis.[29,48,51] The estimated mean survival rate for Zi implants was 74.8% (OR = 1.89; 95% CI, 1.00–3.56), which was statistically significantly lower than the mean survival rate of 85.7% for Ti implants (Fig 2). Consequently, Zi implants had an increased risk of failure of 89% compared with Ti implants. The estimated mean success rate for Zi implants was 91.6% (two studies included) (OR = 1.02; 95% CI, 0.47–2.20), which was not statistically significantly different from the success rate for Ti implants (P = .968) (Fig 3). With regard to MBL, two studies reported that Zi implants had a MBL of 0.89 ± 0.18 mm after 12 to 24 months. The results of the present study favor Ti implants over

Zi implants (mean difference, 0.14 mm). This difference is statistically significant (P = .053) (Fig 4).

Results of Metaregression

A total of 21 studies analyzed the survival rate of 1,948 Zi implants. Survival ranged from 71.2% to 100%. The weighted mean survival rate was 91.5% (95% CI, 87.8–95.2), with follow-up from 6 to 72 months (Fig 5). Owing to the existence of studies with zero variability, it was not possible to estimate the value of heterogeneity I^2 and the corresponding test of nullity. Eleven studies provided success rates, for a sample of 1,250 implants. The weighted mean success rate was 91.6% (95% CI, 85.8–97.5) for Zi implants, with follow-up from 6 to 72 months (Fig 6). The Galbraith plot demonstrates an acceptable homogeneity, except for the study by Pirker when comparing one- versus two-piece implants; the survival rate for one-piece implants was 91.5% (95% CI, 87.5–95.6), while the survival rate for two-piece implants was 93.3% (95% CI, 84.7–100). When connection types were examined, no differences in the survival rate were found (P = .722).

When analyzing the loading protocol, the authors excluded several studies because of inconsistencies in the methodology. Osman et al[48] did not clearly state the protocol used. Similarly, the studies by Grassi et al,[44] Oliva et al,[47] and Kohal et al[31] included patients with both loading protocols, but the results did not make clear distinctions. Hence, these articles were excluded from the analysis. The estimated survival rate for delayed loading was 91.9% (95% CI, 86.2–97.6), and the rate for immediate loading was 91.7% (95% CI, 86.4– 97.1) after a 6- to 72-month follow-up; this difference was not statistically significant (P = .967). The estimated success rate for delayed loading was 90.2% (95% CI, 78.9–100), and the rate for immediate loading was 91.0% (95% CI, 80.9–100); again, the difference was not statistically significant (P = .919).

Ten articles included information about MBL,[18,29,31,40,41,43–45,48,50] for a total of 632 Zi implants. The weighted MBL was 0.89 ± 0.18 mm (95% CI, 0.53–1.25) during 12 to 72 months of follow-up (Fig 7). Because there was zero variability in all the included studies, it is possible to estimate the heterogeneity indicators. Specifically, the heterogeneity among studies was 99.3% of the total variability (intrastudy and interstudy) (I^2 = 0.993). The results of the Cochran test of heterogeneity confirmed its importance (P < .001). In other words, the MBL estimated individually differed significantly compared with the intrastudy variability. The estimated averages for MBL according to the type of connection are as follows: one-piece, 0.93 ± 0.19 mm (95% CI, 0.55–1.30) and two-piece, 1.46 ± 0.57 mm (95% CI, 1.02–1.89). Although only one study examined two-piece connections, the results reached statistical significance (P = .011). Thus, MBL was greater for two-piece connections. With regard to loading protocol, the authors observed a weighted MBL for delayed loading of 0.83 ± 0.29 mm (95% CI, 0.28–1.39), whereas for immediate loading, the MBL was 0.97 ± 0.28 mm (95% CI, 0.42–1.51). There were no significant differences with regard to the loading protocol (P = .747).

Quality Assessment

Three of the 21 studies in the qualitative and quantitative analyses were RCTs. The authors used the RCT checklist of the Cochrane Center and the CONSORT statement to score the quality of the studies.[53,54] Low-to-moderate potential risk of bias was found in the qualitative appraisal of studies. For nonrandomized clinical trials, the authors used NOS to rank quality.[55] The mean (± SD) NOS score for the studies in the present systematic review was 4.64 ± 0.99, failing generally in the selection section. The results indicate acceptable quality of the nonrandomized clinical trials.

DISCUSSION

Advances in the field of dental implantology have occurred in multiple areas. These advancements include, but are not limited to, new surface technologies, materials, and micro and macro designs, as well as a tremendous increase in understanding of the factors affecting MBL and peri-implantitis. These advancements have led to an increase in survival rates of Ti implants (up to 97.2% after 5 years).[56] Studies have also reported survival rates ranging from 97.6% to 100% during a follow-up period of 12 to 36 months.[37,43,52] Biocompatibility, low corrosion, and high resistance represent some of the main characteristics that make Ti the material of choice when designing the vast majority of dental implants. Nevertheless, over the years, multiple studies have reported different types of complications related to this material.[11,15,21,32,57–59] Because of these concerns, other materials have been investigated. Alumina and crystal sapphire aluminium oxide was the first material proposed,[60] but it failed because of low mechanical and physical properties. Yttria-stabilized zirconia ceramic (Y-TZP)—Zi implants—has been shown to be biocompatible, resistant to fracture and compression, and esthetically acceptable, and it presents with low bacterial adherence, making this material a good alternative to Ti for dental implants.[17,19,46,47]

The present meta-analysis found that Zi implants had a 91.5% survival rate and a 91.6% success rate after a mean follow-up of 42.37 months. These findings are in agreement with those of previous studies. In 2009, Andreiotelli et al[17] reported a survival rate of 98% and 84% after 12 and 21 months, respectively. However,

Table 2 Characteristics of the Included Articles

Author, year	Study design	Groups	No. of patients	No. of implants	Follow-up (months)	Survival rate (%)	Success rate (%)	Mean bone loss ± SD (mm)
Becker et al 2015	PC	Test (Zi)	48	48	24	95.8	N/A	N/A
Borgonovo et al 2011	P	Test (Zi)	16	26	24	96.16	91.6	N/A
Borgonovo et al 2013	P	Test (Zi)	10	28	48	100	100	1.631
Borgonovo et al 2015	R	Test (Zi)	13	20	48	100	100	2.1045
Brüll et al 2014	R	Test 1 Test 2	74	55 66	36	96.5	N/A	0.1 ± 0.6
Cannizzaro et al 2010	RCT	Test 1 Test 2	20 20	20 20	12	85 90	N/A N/A	0.90 ± 0.48 0.72 ± 0.59
Cionca et al 2015	P	Test (Zi)	32	49	12	87	N/A	N/A
Gahlert et al 2013	R	Test 1 Test 2 Test 3	57	121	36.75	59.5 90.6 82.4	N/A	N/A
Gahlert et al 2015	P	Test (Zi)	42	42	12	97.6	97.6	0.14 ± 0.88
Grassi et al 2015	PC	Test 1 Test 2	16	16 16	60	93.75 100	96.9	1.29 ± 0.25 1.17 ± 0.33
Jung et al 2015	PC	Test (Zi)	60	71	12	98.6	N/A	0.78 ± 0.79
Kohal et al 2012	PC	Test (Zi)	65	66	12	95.4	N/A	1.31
Kohal et al 2013	P	Test (Zi)	28	56	12	98.2	N/A	1.95 ± 1.71
Oliva et al 2010	P	Test 1 Test 2 Test 3	378	831	60	94.95	92.77 93.57 97.6	N/A
Osman et al 2014	RCT	Control (Ti) Test (Zi)	19	56 73	12	82.1 71.2	N/A N/A	0.18 ± 0.47 0.42 ± 0.40
Payer et al 2013	P	Test (Zi)	20	20	24	95	95	1.29
Payer et al 2015	RCT	Control (Ti) Test (Zi)	22	15 16	24	100 93.3	100 93.3	1.43 ± 0.67 1.48 ± 1.05
Pirkerand Kocher 2009	P	Test 1 Test 2	6 12	6 12	34	0 92	0 92	N/A
Roehling et al 2015	R	Test (Zi)	71	161	84	58.5 88.9 78.6 77.6	58.8 89 78.6 77.6	0.97 ± 0.07
Siddiqi et al 2015	RCT	Control (Ti) Test (Zi)	8 11	48 62	12	88.3 76.5	66.7 67.6	N/A
Spies et al 2015	PC	Test (Zi)	40	53	36	94.2	N/A	0.79

RCT = randomized clinical trial; P = prospective case series; R = retrospective clinical study; PC = prospective cohort study; Ti = titanium implants; MR = macroretention. Zi = zirconia implants; N/A = not applicable; SB = sandblasted; AE = acid etched; MN = machined neck; UC = uncoated; C = coated;

only cohort investigations were evaluated.[17] Several studies have reported lower survival rates with Zi implants compared with Ti implants.[3] The meta-analysis of the RCTs revealed an increased risk of implant failure of 89% when comparing Zi with Ti implants. Recent RCTs comparing Ti with Zi implants have shown low success rates (66.7% and 67%, respectively) for both materials after 1 year of functional loading.[51] However, these results should be interpreted with caution. The surprisingly high failure rate for both groups may be related to the study design rather than to the material. Siddiqi et al[51] used three and four dental implants for mandibular and maxillary overdentures, being one of the maxillary implants inserted in the midpalate. In 2015, Roehling et al[50] reported a survival rate of 77.3% after 7 years of follow-up. We should note that almost half of the failures occurred in narrower-diameter implants (diameter, 3.25 mm), which exhibited the lowest survival rate (58.5%).[50] These results are in accordance with those of previous studies that demonstrate lower survival rates for narrow implants compared with standard-diameter implants.[61]

Implant timing	Implant system	Surface	Length (mm)	Diameter (mm)	Connection	Implant loading protocol
Delayed	ZV3 Zircon Vision	SB	9–13	4.5–5	2-piece implants	Delayed
N/A	WhiteSKY (Bredent)	SB + MN	N/A	N/A	1-piece implants	Immediate
Delayed	WhiteSKY (Bredent)	SB + MN	10–14	4	1-piece implants	Immediate
N/A	WhiteSKY (Bredent)	SB + MN	N/A	N/A	1-piece implants	Immediate
Immediate/delayed	ZV3 Zircon Vision	SB	8	3.5	1-piece implants 2-piece implants	Delayed
Immediate/delayed	Z-look 3 (Z systems)	SB	10–14	3.25–5	1-piece implants	Immediate
Delayed	Zeramex/Zeramex T	N/A	8–12	3.5–5.5	2-piece implants	Delayed
Delayed	Z-look 3 (Z systems)	SB	10–13	3.25 4 5	1-piece implants	Immediate
Early	Pure Ceramic (Straumann)	SLA	8–14	4.1	1-piece implants	Delayed
Immediate Delayed	WhiteSKY (Bredent)	SB + MN	10–14	3.5–5.5	1-piece implants	Immediate/Delayed
N/A	VITA Zahnfabrik	SB + AE	8–14	4–5.5	1-piece implants	Immediate
Immediate/delayed	ZiUnite (Nobel) YTZP	ZiUnite	10–16	4.3–5	1-piece implants	Delayed
Immediate/delayed	ZiUnite (Nobel) YTZP	ZiUnite	10–16	4.3–5	1-piece implants	Immediate/Delayed
Immediate/delayed	CeraRoot	UC C AE	N/A	N/A	1-piece implants	Immediate/Delayed
Delayed	Southern Implants	SB + AE AE	6–11.5	3.8–5	1-piece implants	Immediate
Delayed	WhiteSKY (Bredent)	SB + MN	10–14	3.5–4.5	1-piece implants	Immediate
Delayed	Ziterion vario t Ziterion vario z	N/A N/A	11.5 10–13	4 4	2-piece implants	Delayed
Immediate Immediate	Zirconia block (YTZP)	SB SB + MR	N/A	N/A	1-piece implants	Delayed
Early	Z-look 3 (Z systems)	SB	10–13	3.25–5	1-piece implants	Delayed
Delayed	Southern Implants	SB + AE SB + AE	6–11.5	3.8–5	1-piece implants	Immediate
Immediate/delayed	Ziraldent FR1	SB	9–14	N/A	1-piece implants	Immediate

The present systematic review includes 12 implant systems, most of which involved a sandblasted surface with different degrees of roughness.[18,29–31,36–46,48–52] The one exception is the 2010 study by Oliva et al[47] in which two groups were described: one group was composed of implants coated with stable bioactive ceramic and the other group was composed of uncoated Zi implants. The coated Zi implants had a lower survival rate (92.77%) than the uncoated implants (93.57%) after 5 years,[47] although the difference was not statistically significant. Similarly, the results of a 2014 study by Manzano et al[21] suggest that the treated surface of Zi implants can increase BIC, reducing the incidence of early implant failure and presenting a reversal torque similar to the surface-treated Ti implants.

With regard to MBL, the present review found a difference of 0.14 mm, favoring Ti implants after 12 to 24 months. This result is comparable to that in a previous systematic review in which 38% of the included studies found a significant MBL around Zi implants.[62] In addition, a MBL of 0.89 ± 0.18 mm was found for Zi implants after an observation period of 12 to 24 months.

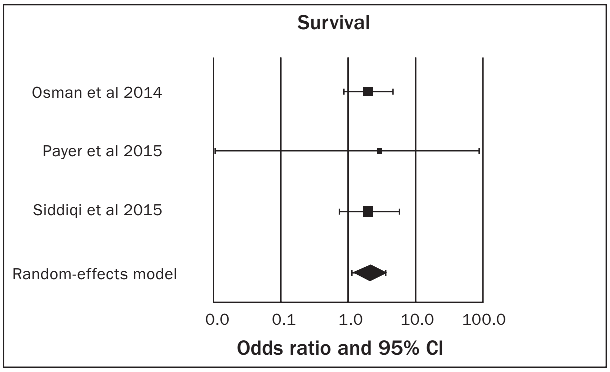

Fig 2 Meta-analysis for implant survival.

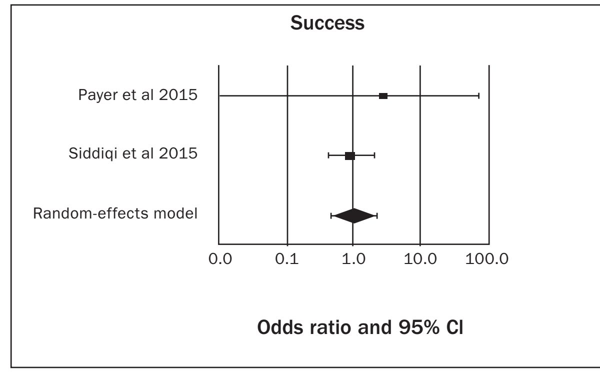

Fig 3 Meta-analysis for implant success.

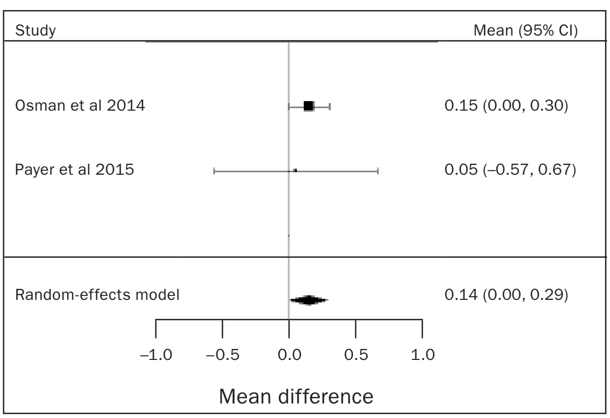

Fig 4 Meta-analysis for mean bone loss.

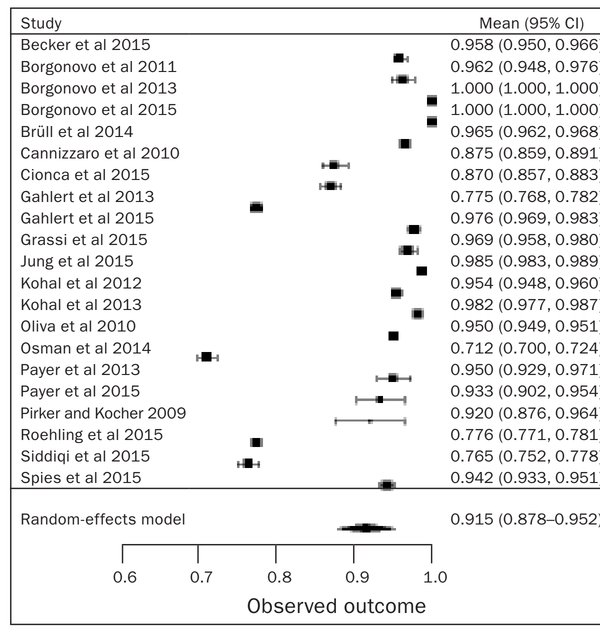

Fig 5 Survival rates of Zi implants.

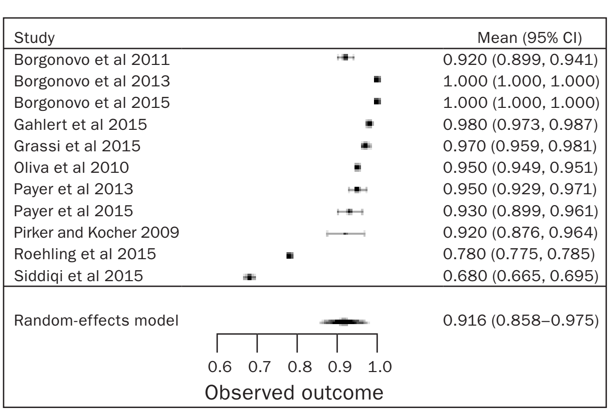

Fig 6 Success rates of Zi implants.

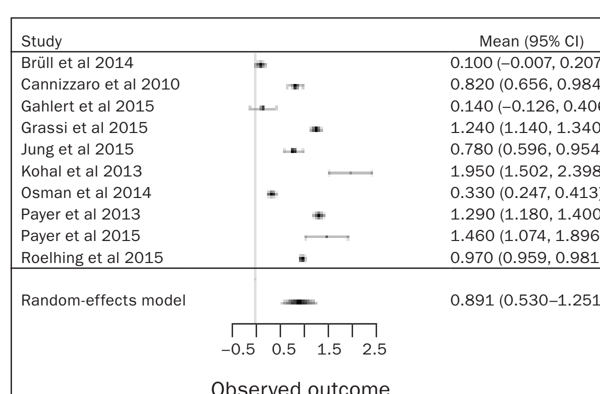

Fig 7 Mean bone loss for Zi implants.

The MBL for one-piece implants was 0.93 ± 0.19, while the MBL for two-piece implants was 1.46 ± 0.57 mm. These findings are in agreement with the findings reported by Sanz et al.[63] When comparing one-piece and two-piece implants, the authors found mean volume changes of –0.12 mm (± 0.27) in the two-piece group and –0.03 mm (± 0.29) in the one-piece group, with no statistically significant differences between them. Furthermore, the loading protocol did not alter the survival rate of Zi implants (91.7% for immediate loading and 91.9% for delayed loading). The same is true for MBL (immediate approach, 0.97 ± 0.28 mm; delayed approach, 0.83 ± 0.29 mm).

Researchers have reported that Zi implants present with a lower bacterial attachment compared with Ti implants,[64] which may lead to less inflammation and ultimately to a lower prevalence of mucositis, peri-implantitis, or both. However, because of heterogeneity among the included studies, peri-implant parameters such as bleeding on probing, plaque index, and probing pocket depths could not be statistically analyzed.

Although more RCTs are needed to validate these findings, Zi implants with treated surfaces exhibited certain advantages over conventional Ti implants despite their slightly lower survival and success rates. Future investigations should focus on well-designed RCTs with long-term follow-up. In addition, studies pertaining to regenerative procedures around Zi implants are essential to further examine the potential of this material.

The heterogeneity of some studies in this investigation does not allow us to conduct more individualized analyses. Also, the lack of long-term studies of Zi implants with treated surfaces represents a major flaw. Finally, as a consequence of MBL's being evaluated radiographically, only mesial and distal surfaces could be examined.

CONCLUSIONS

In certain situations, specifically anterior esthetic areas with a thin biotype, Zi implants may be an alternative to Ti implants. Within the limitations of this study and the limited number of RCTs comparing the performance of Ti versus Zi implants, Zi implants exhibited a lower survival rate than that of Ti implants (OR = 1.89) and a higher MBL (mean difference, 0.14 mm), which favors Ti implants.

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