Differences in Titanium, Titanium-Zirconium, Zirconia Implants Treatment Outcomes: a Systematic Literature Review and Meta-Analysis

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ABSTRACT

Objectives: The objective of this systematic review is to test the hypothesis that treatment with titanium, titanium-zirconium and zirconia dental implants has different clinical outcomes in survival rate, marginal bone loss, bleeding on probing, plaque control record, and probing depth.
Material and Methods: A systematic electronic search through the PubMed (MEDLINE) and Cochrane Library databases was performed to identify studies published between January 1, 2013 and January 1, 2023 containing a minimum of 10 patients per study comparing titanium (Ti), titanium-zirconium (Ti-Zr), and zirconia (Zr) dental implants. Ti, Ti-Zr, and Zr dental implant clinical outcomes were determined by evaluating survival rate, marginal bone level, bleeding on probing, probing depth, plaque control record. Quality and risk-of-bias assessment were evaluated by Cochrane risk of bias tool.
Results: A total of 1361 articles were screened, with 10 meeting the inclusion criteria and being utilized for this systematic review and meta-analysis. A total of 301 patients with 637 implants (304 Ti, 134 Ti-Zr, and 199 Zr) were evaluated, showing a survival rate of 97.7% for Ti, 98.6% for Ti-Zr, and 93.8% for Zr implants respectively. In a meta-analysis, no difference in marginal bone level was found between Ti, Ti-Zr, and Zr implants (P = 0.84).
Conclusions: Dental implant survival rate was lower in zirconia group. Assessment of marginal bone loss and bleeding on probing showed better results with titanium-zirconium dental implants. Plaque control result was similar in all groups. Due to limited sample size assessed it was not possible to obtain conclusion on probing depth parameter.

Keywords: dental implants; systematic review; titanium; zirconia.

Accepted for publication: 29 September 2023
To cite this article:
Haimov E, Sarikov R, Haimov H, Juodzbalys G.
Differences in Titanium, Titanium-Zirconium, Zirconia Implants Treatment Outcomes: a Systematic Literature Review and Meta-Analysis
J Oral Maxillofac Res 2023;14(3):e1
URL: http://www.ejomr.org/JOMR/archives/2023/3/e1/v14n3e1.pdf
doi: 10.5037/jomr.2023.14301

INTRODUCTION

Since being introduced by Brånemark in 1965, dental implants made from titanium (Ti) has revolutionized the field, offering a reliable, safe, and successful method for tooth replacement in various indications [1,2]. Primarily, the advantages of Ti materials are their excellent physical properties, that is, high resistance to corrosion, low module of elasticity, and considerable fatigue strength [3]. However, the greyish colour and potential for corrosion are often considered drawbacks, as they can impact the health and appearance of peri-implant tissues, leading to aesthetic disadvantages [4].

In recent years, yttria-stabilized tetragonal zirconia (Zr) polycrystal (Y-TZP) has emerged in dentistry as an implant material due to its aesthetic, physical and mechanical properties [5]. Zr-based materials have been claimed as a biomaterial with a high chemical stability that avoid the release of toxic products to the surrounding tissues [6], it provides stimulation of osteogenic cells during osseointegration in combination with unique mechanical characteristics such as high fracture toughness, fatigue resistance, high bending strength, high corrosion resistance, and radiopacity [7]. Compared to Ti, Zr is inferior in osseointegration and requires improvement by surface modification [8] although, few studies have demonstrated that Zr implants have similar results [5].

While implant therapy is highly predictable and boasts excellent long-term survival rates, complication may still arise that can jeopardize both short- and long-term success [9]. Nowadays, not only successful osseointegration but also clinical symptoms determining tissue behaviour such as soft tissue integration, marginal bone loss, bleeding on probing (BoP) and plaque control record (PCR) outcomes have become important factors for long-term clinical success [10].

Therefore, the aim of this systematic review is to test the hypothesis that treatment with titanium, titanium-zirconium and zirconia dental implants has different clinical outcomes in survival rate, marginal bone loss, bleeding on probing, plaque control record, and probing depth.

MATERIAL AND METHODS

Protocol and registration

The review was conducted in accordance with the preferred reporting items for systematic reviews and Meta-analysis (PRISMA) statement for reporting systematic reviews [11] (Figure 1).

Methods of the analysis and inclusion criteria were specified and documented in a protocol, and registered in PROSPERO, an international prospective register of systematic reviews. Registration number: CRD42023424785. The protocol can be accessed at: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=424785

Focus question

The focus question was created according to the Patient, Intervention, Comparison and Outcome (PICO) framework as described in Table 1.

The focus question: Are there any differences in clinical treatment outcomes with titanium, titanium-zirconium, and zirconia dental implants?

Types of publication

The review included studies on humans published in the English language. Literature reviews, meta-analysis, systematic reviews, letters, editorials, PhD theses, and abstracts lacking full text were excluded.

Information sources

The information source was the MEDLINE (PubMed) and Cochrane Library databases.

Types of studies

In this review were included randomized controlled trials (RCTs), controlled clinical trials (CCTs), prospective or retrospective cohort studies published from January 1, 2013 to January 1, 2023.

Population

Adult healthy patients underwent oral rehabilitation with Ti, titanium-zirconium (Ti-Zr), and Zr dental implants.

Search strategy

According to the PRISMA guidelines [12] for the search, the following keywords were used in combination: “titanium-zirconium versus titanium dental implants” AND “zirconia versus titanium implants “AND “zirconia dental implants“ AND “titanium-zirconium implant”.

The search was restricted to English language and articles published from January 1, 2013 to January 1, 2023.

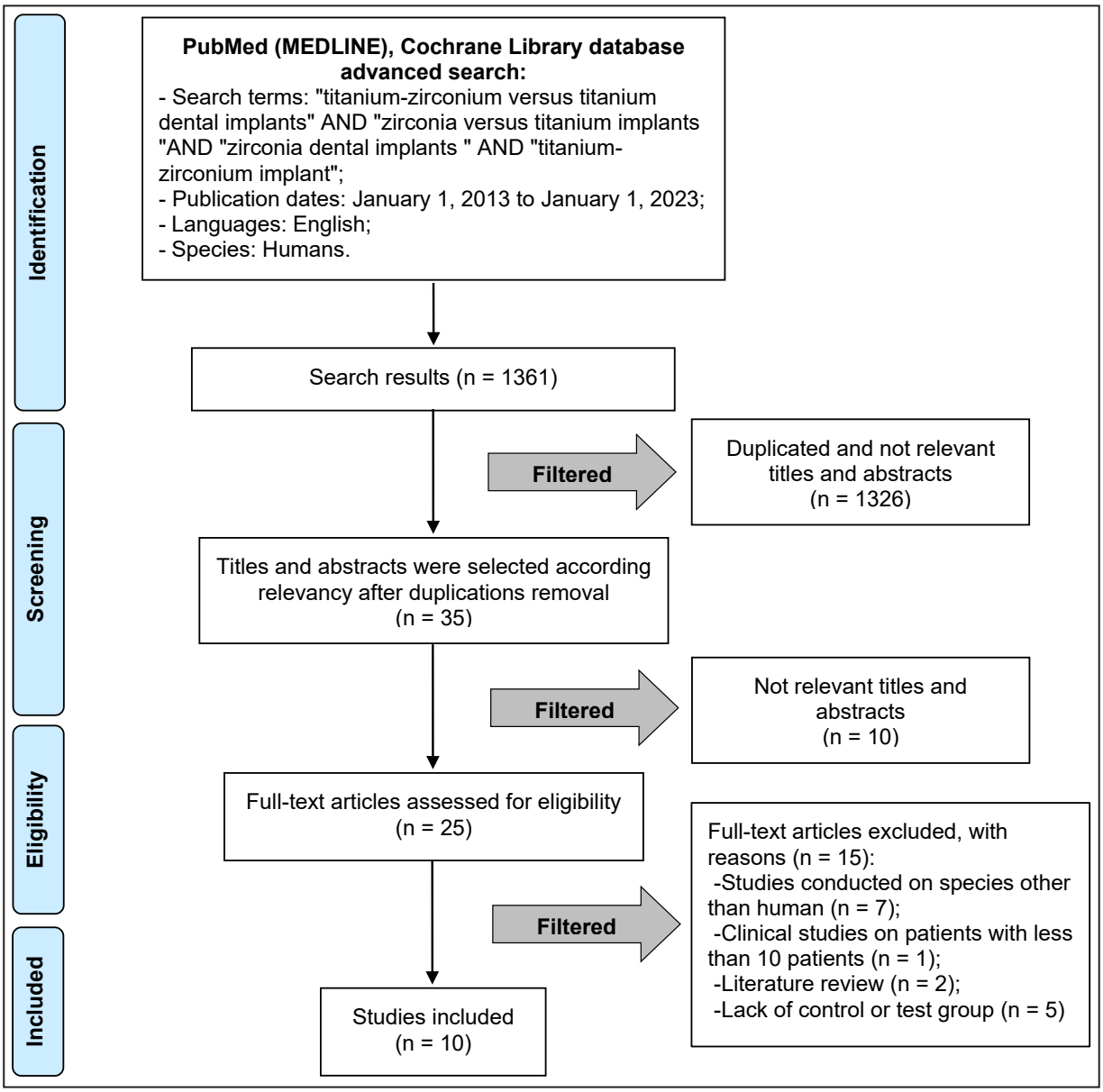

Figure 1. PRISMA flow diagram summarizing the search strategy and study selection.

Table 1. PICO guidelines

Patient and population (P)	Healthy adult patients underwent titanium, titanium-zirconium, and zirconia dental implant placement
Intervention (I)	Adult healthy patients underwent oral rehabilitation with titanium, titanium-zirconium, and zirconia dental implants and evaluated following clinical symptoms: survival rate, marginal bone level, bleeding on probing, probing depth, plaque control record
Comparison (C)	Comparison of clinical symptoms and implant survival after oral rehabilitation with titanium, titanium-zirconia and zirconium dental implants
Outcomes (O)	Titanium, titanium-zirconium, and zirconia dental implant clinical outcomes as assessed by evaluating survival rate, marginal bone level, bleeding on probing, probing depth, plaque control record
Focus question	Are there any differences in clinical treatment outcomes with titanium, titanium-zirconium, and zirconia dental implants?

Inclusion criteria for the selection

Investigations were considered eligible when they met the following criteria:

- Clinical studies published in English between January 1, 2013 and January 1, 2023 on patients with a sample size of at least 10 patients.
- 18-year-old and above systemically healthy patients.

- Studies with quantitative outcomes including the survival rate of RCTs, CCTs, prospective or retrospective cohort studies.
- At least 6 months of follow-up after implant placement.
- Studies, which evaluated the clinical outcome of Ti, Ti-Zr, Zr dental implants.

Exclusion criteria

The exclusion criteria were as follows:
- Case series, case reports, cross-sectional studies, reviews.
- Studies conducted on species other than human.
- Studies written in language other than English.
- RCTs that registered only one type of implant.

Data extraction and data items

According to the aim and tasks of the review in the form of variables, data extracted from the articles were according to the aim and tasks of the review. The following data items were extracted from the articles included in this review:
- First author and publication year.
- Study design.
- Total number of patients.
- Total number of implants and type of implant.
- Mean age.
- Male/female ratio.
- Last follow-up period.
- Implant system.
- Implant failure and implant survival outcomes.
- Outcome measures namely marginal bone level (MBL), BoP, probing depth (PD), and PCR.

Selection process of articles

The research for this review was compiled in few stages. The first stage was to identify articles based on the keywords mentioned earlier. The titles and abstracts of the identified reports were independently screened by two reviewers (E.H. and R.S.) A third reviewer (G.J.) checked possible inconsistencies and consulted reviewers, when consensus could not be reached. All database duplications were removed. After full-text analysis, publications were further assessed for relevance and compliance with the selection criteria. Eligible publications were included in this systematic review. Reviewers were calibrated and Cohen's kappa coefficient (κ) values for inter-rater reliability was calculated for abstract and title evaluation after selecting 10% of publications.

Risk of bias

The risk of bias (e.g., lack of information, surgeries performed by single operator, specific age group, sex scission, and low objectives number) that can affect the cumulative evidence was assessed across the studies. The risks were indicated.
The Cochrane Collaboration's tool for assessing the risk of bias [13] was used to assess bias of the studies that can affect cumulative evidence.
If there was only one minus box or two question-mark boxes, it was indicative of existent bias for the respective study included. Only if all boxes were plus could it be said that no bias was found.

Synthesis of the results

Appropriate data of interest on the previously stated data items were collected and organized into the following fields of tables: year of publication, number of patients, study design and male/female ratio, type of implant used, total patients' dropout, implant system and implant lost, clinical data outcomes.

Statistical analysis

Mendeley® version 2.79 (Elsevier; London, UK) reference manager software was used for article management. The meta-analysis was conducted in IBM SPSS® Statistics software version 29.0 (IBM Corp.; Armonk, New York, USA). Numerical values are presented as mean and standard deviation (M [SD]). The level of P-value was set considerably statistically significant at < 0.05.

RESULTS

Study selection and exclusion

The search delivered 1361 search results (Figure 1). Preliminary exclusion was made by the title and its relevancy and later by abstract relevancy. After title checking and removal of duplicates, 35 articles remained. Ten articles were excluded due to not relevant titles and abstracts. Of the 25 articles, 15 were filtered out because they did not meet the inclusion and exclusion criteria: studies conducted on species other than human (n = 7); clinical studies on patients with < 10 patients (n = 1); literature review (n = 2); lack of control or test group (n = 5). A total of 10 studies were included in this review, all the studies were related to outcome associated to Ti, Ti-Zr and Zr implants (Figure 1 and Table 2). The data were included on 301 patients with 637 implants (304 Ti, 134 Ti-Zr and 199 Zr).

Table 2. Description of studies included in the review

Study	Year of publication	Study design	Follow-up	Population	Patients	Gender	Control and test group
					N	Male/ female	
Benic et al. [14]	2013	Prospective randomized clinical trial	1 year	Patients in need of an implant-supported crown	40	NR	Control group: Ti 4.1 mm diameter implant. Test group: Ti-Zr 3.3 mm diameter implant
Bienz et al. [15]	2021	Prospective randomized clinical trial	6 months	Prerequisite were two missing adjacent teeth	42	8/12	Control group: Zr implants. Test group: Ti implants
Hassouna et al. [16]	2022	Prospective cohort study	5 years	Replacement of a single-tooth in the maxillary premolar area	28	NR	Control group: one-piece Ti implant. Test group: one-piece Zr implant
Ioannidis et al. [17]	2015	Prospective randomized clinical trial	3 years	Patients in need of an implant-supported crown	40	NR	Control group: Ti 4.1 mm diameter implant. Test group: Ti-Zr 3.3 mm diameter implant
Koller et al. [18]	2020	Prospective randomized clinical trial	6.5 years	Patients had edentulous space ≤ 3 missing teeth as well adequate horizontal and vertical bone for implants ≥ 10 mm in length and 4 mm diameter	22	13/9	Control group: two-piece implants made of yttria-stabilized Zr. Test group: standard two-piece Ti implants
Müller et al. [19]	2015	Prospective randomized clinical trial	5 years	Patients who had completed the core study were invited to participate in the follow-up study to collect long-term data	47	24/23	Control group: Ti implants. Test group: Ti-Zr implants
Osman et al. [20]	2014	Prospective randomized clinical trial	1 year	Patients with functional problems in their use of complete dentures	24	15/4	Control group: one-piece Ti implant. Test group: one-piece Zr implant
Payer et al. [21]	2015	Prospective randomized clinical trial	2 years	Patients providing tooth gaps up to three missing units with a sufficient amount of horizontal and vertical bone for the placement of implants	22	13/9	Control group: two-piece standard Ti implants. Test group: two-piece yttria-stabilized Zr implants
Siddiqi et al. [22]	2015	Prospective randomized clinical trial	1 year	Patients involved surgical and prosthodontic rehabilitation of 24 completely edentulous participants with implant overdentures	24	15/4	Control group: implants were made from Ti. Test group: Zr implants were used
Tolentino et al. [23]	2016	Prospective randomized clinical trial	1 year	Patients for single-unit prosthetic rehabilitation in contra lateral molar sites of the mandible were included in the study	12	4/8	Control group: cpTi implants. Test group: Ti-Zr implants

N = number; NR = not reported; Ti = titanium; Zr = zirconia.

Inter-rater reliability kappa of 0.88 was achieved, indicating strong reliability of agreement.

Assessment of risk of bias

The risk of bias was evaluated, and bias was observed in all studies. Benic et al. [14] showed only plus boxes so no bias was found. Bienz et al. [15] presented only one minus box and one question-mark box, Hassouna et al. [16] showed only plus boxes so no bias was found. Ioannidis et al. [17] had only one question-mark box while Koller et al. [18] and Müller et al. [19] showed only one question-mark box. The highest amount of bias was observed in Osman et al. [20] study (two minus boxes and one question-mark), Payer et al. [21] and Siddiqi et al. [2] showed only plus boxes so no bias was found, Siddiqi et al. [22] showed only plus boxes so no bias was found. Tolentino et al. [23] presented only one minus box and one question-mark box, Figure 2 shows the risk of bias for all clinical studies included in this systematic review (Table 3).

Study characteristics

The characteristics and detailing of included studies are presented in Table 4 and 5. All the ten included clinical trials were of prospective design. In total, a pool of 301 patients were used in this present systematic review and there were 28 total dropouts. Three studies [14,16,17] did not report how many male and female patients were treated; thus, a total of 92 males and 69 females were reported.

Total number of implants is 637, 304 were Ti, 134 were Ti-Zr and 199 were Zr implants (Table 4). The amount of implant lost during the follow-up period was as follows: 22 Ti (3.4%), 1 Ti-Zr (0.2%), and 45 Zr (7.1%) implant. Four studies [17-19,21] used two-piece implant, another four studies [14,16,20,22] used one-piece implant, [15,23] did not report the type of setting used.

Regarding the implant system, four studies [14,15,17,23] used Straumann® (Straumann AG; Basal, Switzerland), other three studies [18,19,21] used Ziterion® (Ziterion GmbH; Uffenheim, Germany),

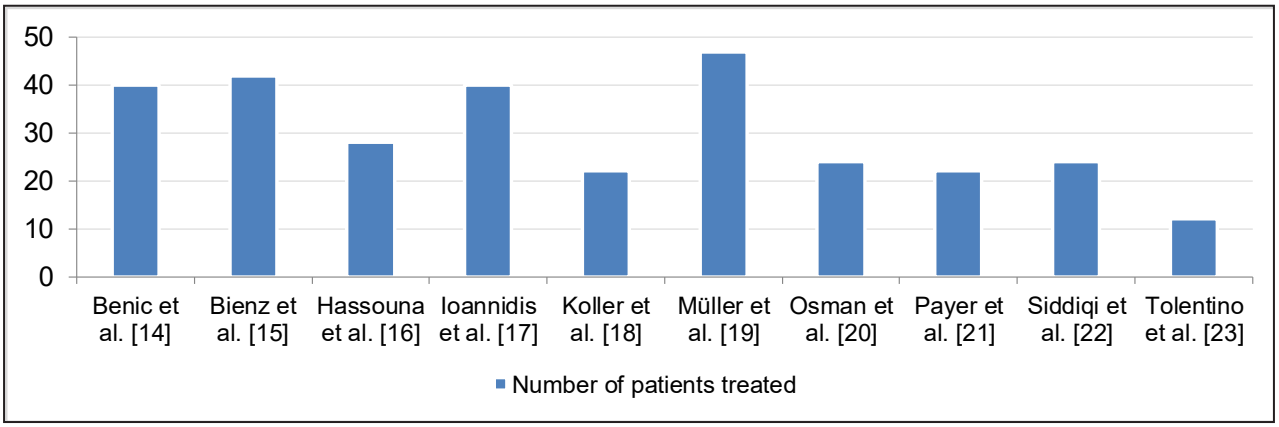

Figure 2. Number of patients treated.

Table 3. The Cochrane Collaboration's tool for assessing the risk of bias

Study	Random sequence generation	Allocation concealment	Blinding (participants and personnel)	Blinding (outcome assessment)	Incomplete outcome data	Selective reporting	Other bias
Benic et al. [14]	+	+	+	+	+	+	+
Bienz et al. [15]	+	+	?	-	+	+	+
Hassouna et al. [16]	+	+	+	+	+	+	+
Ioannidis et al. [17]	+	+	-	+	+	+	+
Koller et al. [18]	+	+	?	+	+	+	+
Müller et al. [19]	+	+	+	?	+	+	+
Osman et al. [20]	+	-	-	?	+	+	+
Payer et al. [21]	+	+	+	+	+	+	+
Siddiqi et al. [22]	+	+	+	+	+	+	+
Tolentino et al. [23]	+	?	-	+	+	+	+

+ = yes; - = no; ? = unclear.

Table 4. Characteristics of the included studies

Study	Age	Implant					
		Dropout	Ti implant	Zr implant	Implant system	Implants lost	1 or 2 pieces
	Mean (SD)	N	N	N		N	
Benic et al. [14]	NR	2	20	20 (Ti-Zr)	Straumann®	0	1
Bienz et al. [15]	55	2	42	42 (Ti-Zr)	Straumann®	0	NR
Hassouna et al. [16]	NR	0	14	140	NR	0	1
Ioannidis et al. [17]	NR	NR	20	20 (Zr)	Straumann®	NR	2
Koller et al. [18]	46 (26)	0	15	16 (Zr)	Ziterion® (Vario T; Ziterion)	1 Ti / 2 Zr	2
Müller et al. [19]	72 (8)	16	47	47 (Zr)	Ziterion® (Vario T; Ziterion)	1 Ti/1 Ti-Zr	2
Osman et al. [20]	62 (17)	5	56	73 (Zr)	Southern implants®	10 Ti/21 Zr	1
Payer et al. [21]	46 (26)	0	15	16 (Zr)	Ziterion® (Vario T; Ziterion)	1 Zr	2
Siddiqi et al. [22]	62 (16)	3	70	80 (Zr)	Southern implants®	10 Ti/21 Zr	1
Tolentino et al. [23]	43.3 (6)	0	5	5 (Ti-Zr)	Straumann®	0	NR

Ti = titanium; Zr = zirconia; Ti-Zr = titanium-zirconium; SD = standard deviation; N = number; NR = not reported;

Table 5. Clinical data of the included studies

Study	Follow-up	SR	SR	MBL	MBL	BoP	BoP	PD	PD	PCR	PCR
		Ti (%)	Zr (%)	Ti (mm)	Zr (mm)	Ti (%)	Zr (%)	Ti (mm)	Zr (mm)	Ti (%)	Zr (%)
				Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Benic et al. [14]	1 year	100	100*	-0.46 (0.5)	-0.5 (0.63)*	12.5 (12.9) (P > 0.683)	12.7 (19.1)* (P > 0.683)	NR	NR	6.2 (12) (P > 0.05)	3.9 (9.3)* (P > 0.05)
Bienz et al. [15]	6 months	100	100	NR	NR	32.5 (27.8) (P < 0.05)	21.7 (23.6) (P < 0.05)	2.6 (0.4)	2.4 (0.4)	75 (29.4) (P < 0.0001)	68.3 (31.9) (P < 0.0001)
Hassouna et al. [16]	5 years	100	100	-1.8 (0.24)	-1.77 (0.41)	NR	NR	3.5 (0.6) (P < 0.01)	3.3 (0.5) (P < 0.01)	NR	NR
Ioannidis et al. [17]	3 years	97.3	98.7*	-0.38 (0.55) (P > 0.05)	-0.5 (0.9)* (P > 0.05)	20 (19.1) (P > 0.05)	13.8 (17.9)* (P > 0.05)	2.9 (0.8) (P > 0.05)	2.6 (0.8)* (P > 0.05)	7.7 (11.9) (P > 0.05)	10 (16.4)* (P > 0.05)
Koller et al. [18]	6.5 years	93.3	87.5	-1.17 (0.73) (P > 0.05)	1.38 (0.81) (P > 0.05)	12.6 (7.6) (P < 0.01)	16.4 (6.16) (P < 0.01)	NR	NR	15.2 (15.58) (P > 0.05)	11.07 (8.11) (P > 0.05)
Müller et al. [19]	5 years	92.6	95.8*	-0.61 (0.83) (P > 0.05)	-0.6 (0.69)* (P > 0.05)	NR	NR	NR	NR	NR	NR
Osman et al. [20]	1 year	95.8	90.9	-0.18 (0.47)	-0.42 (0.4)	NR	NR	NR	NR	NR	NR
Payer et al. [21]	2 years	100	93.3	-1.43 (0.67)	-1.48 (1.05)	7.4 (3.39)	9.1 (4.34)	NR	NR	NR	NR
Siddiqi et al. [22]	1 year	98.6	91.2	-0.125 (0.34)	-0.25 (0.23)	NR	NR	1.59 (0.5)	2.2 (0.61)	NR	NR
Tolentino et al. [23]	1 year	100	100*	-0.35 (0.24)	-0.32 (0.27)*	10	10*	3.051 (P > 0.05)	3.1* (P > 0.05)	NR	NR

*Titanium-zirconium.
SR = survival rate; MBL = marginal bone loss; BoP = bleeding on probing; PD = probing depth; PCR = plaque control record; Ti = titanium; Zr = zirconia; SD = standard deviation; NR = not reported.

while [20,22] used Southern Implants® (Southern Implants; Irene, Centurion, South Africa), and [16] did not mention the company of the implants.

Nine of the ten included studies reported the number of failed implants [14-16,18-23], also nine studies [14,16-23] reported about MBL level. BoP was reported by 6 studies [14,15,17,18,21,23] and PD by five [15-17,22,23] the minimum follow-up period of the outcomes variables (survival rate, MBL, BoP, PD and PCR) was six months and the maximum follow-up period was eighty months. Eight of the studies [14-18,21-23] proceeded with a flap technique,

while one study [20] used flapless approach. The patients received a preoperative antibiotics prophylaxis in five of the studies [14,16-18,22] and five studies [15-18,21] reported about prescription of postoperative antibiotics for the patients. A postoperative instruction on chlorhexidine rinse was made in six of the clinical trials [14-17,22,23] , while only three studies followed a preoperative mouth rinse protocol [15,16,22].

Implant features

Implants were classified according to their diameter and length. For the Ti implants Hassouna et al. [16] used 12 mm implant length, while [18,21] used 11.5 mm implants length, other three studies [14,15,17] used 8 mm in length, Müller et al. [19] and Osman et al. [20] used three types of length (8, 10, 11.5 mm).
For the Zr and Ti-Zr implants Hassouna et al. [16] used implant length of 12 mm, three other studies [14,15,17] used implant length of 8 mm, while Koller et al. [18] and Payer et al. [21] used three types of length (10, 11.5 and 13 mm), Müller et al. [19] and Osman et al. [20] used also three types of implant length (8, 10 and 10.5 mm), two another studies [22,23] did not mentioned implant length.
Regarding the diameter, Koller et al. [18] reported regular diameter implants for both Ti and Zr implants. Two studies [15,21] used a regular diameter (4.1 mm) for both Ti and Zr implants, Benic et al. [14] and Ioannidis et al. [16] also used regular diameter (4.1 mm) for Ti implants but used a narrow diameter (3.3 mm) for the Ti-Zr implants, Hassouna et al. [16] used a regular diameter (4.5 mm) for Ti implants and narrow diameter (3.6 mm) for Zr implants, two studies [20,22] used reported the utilization of regular and wide diameter for Ti and Zr implants (3.8 to 5 mm), Müller et al. [19] and Tolentino et al. [23] placed a narrow diameter (3.3 mm) for the both implants.

Survival rate

In total 637 implants were placed (304 Ti, 134 Ti-Zr and 199 Zr), the number of failed implants was 68 (22 Ti 1, Ti-Zr and 46 Zr) resulting in overall implant survival rates of 92.76% (282/304) for Ti group and 86.12% for the Zr group (Table 5).

Marginal bone loss

For MBL parameter nine of the included clinical trials analysed the MBL measurements. Koller et al. [18], found that Zr implants were associated with a mean MBL of 1.51 (0.68) mm at 30 months and 1.38 (0.81) mm at 80 months (Table 5). The corresponding values for Ti implants were 0.92 (0.72) mm and 1.17 (0.73) mm. No significant intragroup difference from 30 to 80 months was noted for the Ti or Zr group ($P > 0.05$). Ioannidis et al. [17] from the 1 to the 3-year examination, median change in mean MBL measured 0.38 mm (mean 0.55 mm) for the Ti implants and 0.5 mm (0.5 [0.9] mm) for the Ti-Zr implants. The difference between the groups was not statistically significant ($P > 0.05$). Payer et al. [21] with follow-ups of 6, 12, 18, 24 months registered mean MBL measurements for Ti implants mean MBL was 0.16 (0.24) mm, 0.4 (0.38) mm, 0.88 (0.56) mm, 1.15 (0.73) mm and 1.43 (0.67) mm ($P < 0.001$); for Zr implants yielded 0.67 (0.95) mm, 1.16 (1.01) mm, 1.2 (0.76) mm and 1.48 (1.05) mm. Müller et al. [19] showed no significant differences in MBL between the Ti and Ti-Zr the group, assessed 60 months after implant placement ($P > 0.05$). The mean change in the Ti-Zr group was -0.6 (0.69) mm and in the Ti group -0.61 (0.83) mm, ranging from -3.57 to 0.16 mm and from -3.65 to 0.44 mm. Tolentino et al. [23] after 1 year of follow-up registered -0.35 (0.24) mm of MBL for Ti implants and for Ti-Zr implants -0.32 (0.27) mm. Osman et al. [19] registered after 1 year follow-up -0.18 (0.47) mm of MBL for Ti implants and ranging of -0.42 (0.4) mm for Zr implants. Siddiqi et al. [22] registered -0.125 (0.34) mm of MBL for Ti implants and -0.25 (0.23) mm for Zr implants after 1 year of follow-up. Benic et al. [14] had -0.46 (0.5) mm MBL for Ti implants and -0.5 (0.63) mm for Ti-Zr implants. Hassouna et al. [16] had -1.8 (0.24) mm MBL for Ti implants and -1.77 (0.41) mm for Zr implants. No significant difference was found between the different groups at follow-up times (Table 5).

Bleeding on probing

Only six studies showed information about BoP (Table 5). For Payer et al. [21] Evaluation of BoP revealed 7.4 (3.39)% after 24 months for Ti implants and for Zr implants 9.1 (4.34)% after 24 months. Tolentino et al. [23] after 1 year of loading revealed the same number 10% for both Ti and Ti-Zr implants. Ioannidis et al. [17] after 3 years follow-up showed for Ti implants 20 (19.1)% and 13.8 (17.9)% for Ti-Zr implants ($P > 0.05$). Benic et al. [14] registered after 1 year of follow-up 12.5 (12.9)% for Ti implants and 12.7 (19.1)% for Ti-Zr implants ($P > 0.683$). Koller et al. [18] registered after 80 months follow-up 12.6 (7.6)% for Ti implants and 16.4 (6.16)% for Zr implants ($P < 0.01$). For the shortest follow-up period of 6 months Bienz et al. [15] showed 32.5 (27.8)% for Ti implants and 21.7 (23.6)% for Zr implants ($P < 0.05$). No significant overall difference between Ti and Zr implants could be observed.

Probing depth

Only five studies showed information about this parameter (Table 5). Ioannidis et al. [17] registered 2.9 (0.8) mm for Ti implants and 2.6 (0.8) mm for Ti-Zr implants after 3 years follow-up (P > 0.05). For the 1-year follow-up, Tolentino et al. [23] showed same number 3.1 mm for both implants (P > 0.05). Siddiqi et al. [22] wrote 1.59 (0.5) mm for Ti implants and 2.2 (0.61) mm for Zr implants. Bienz et al. [15] registered same number of 2.5 (0.4) mm for both Ti and Zr implants after 6 months follow up. The longest follow up period of 5 years was observed in Hassouna et al. [16] that reported 3.5 (0.6) mm for Ti implants and 3.3 (0.5) for Zr implants (P < 0.01).

Plaque control record

Four of the included clinical trials analysed the PCR (Table 4) [14,15,17,18]. One of the studies reported two follow-up periods of 30 months and 80 months [18] in the first period the plaque index was 21.04 (6.09)% for Ti implants and 23.68 (10.74)% for Zr implants (P > 0.05). For the second period the plaque index was 15.2 (15.58)% for Ti implants and 11.07 (8.11)% for Zr implants. Ioannidis et al. [17] with one follow-up period after 3 years registered 7.7 (11.9)% for Ti implants and 10 (16.4)% for Ti-Zr implants (P > 0.05). Another study [14] with 1 year follow-up reports PCR of 6.2 (12)% for Ti implants and 3.9 (9.3)% for Ti-Zr implants (P > 0.05), the last study [15] with the lowest period of six months follow-up reported an overall of 75 (29.4)% for Ti implants and 68.3 (31.9)% for Zr implants (P < 0.0001).

Reliability of studies

Details of the treatment procedures of the included studies (Table 6), the number of patients treated (Figure 2), the follow-up period (Figure 3). A comparison between the studies was completed.

Meta-analysis

Meta-analysis was to be conducted only if there were studies of similar comparison, reporting identical

Table 6. Details of the treatment procedures of the included studies

Study	Flap technique	Preoperative antibiotic prophylaxis	Preoperative chlorhexidine rinse	Postoperative antibiotic prophylaxis	Postoperative chlorhexidine prophylaxis
Benic et al. [14]	Flap	Yes	No	No	Yes
Bienz et al. [15]	Flap	No	Yes	Yes	Yes
Hassouna et al. [16]	Flap	Yes	Yes	Yes	Yes
Ioannidis et al. [17]	Flap	Yes	No	Yes	Yes
Koller et al. [18]	Flap	Yes	No	Yes	No
Müller et al. [19]	NR	No	No	No	No
Osman et al. [20]	Flapless	No	No	No	No
Payer et al. [21]	Flap	No	No	Yes	No
Siddiqi et al. [22]	Flap	Yes	Yes	No	Yes
Tolentino et al. [23]	Flap	No	No	No	Yes

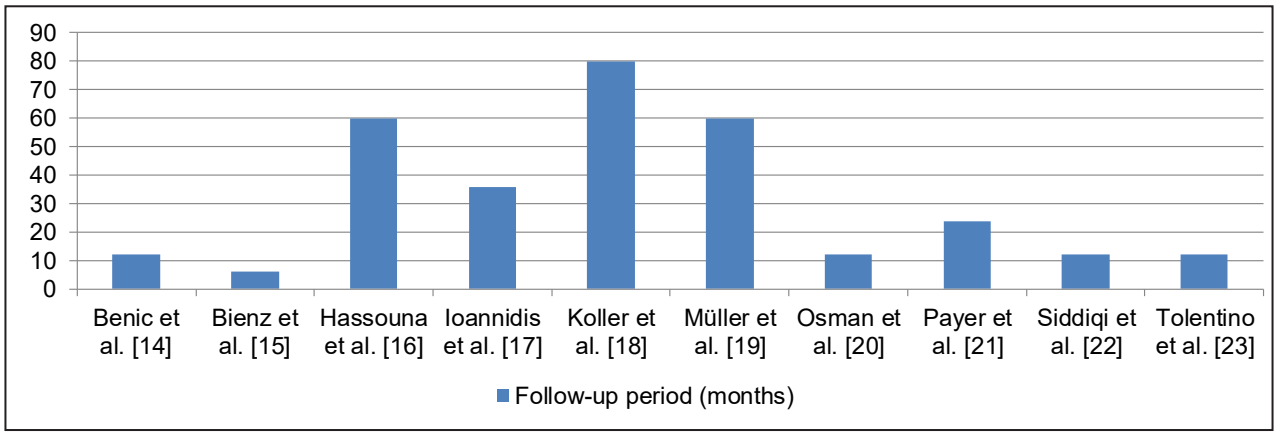

Figure 3. Follow-up period (months).

outcome measures. However, the included studies of the meta-analysis revealed substantial variations in study design, i.e., gender effects, marginal bone loss, BoP. Consequently, a well-defined meta-analysis was not applicable. Instead, a meta-analysis (with random effect) was conducted using chi square test. All other studies were heterogeneous, so meta-analysis was not applicable. For the MBL evaluation the Cohran's Q was 0.35 and P value 0.84 that mean that there were not significant changes between the groups in MBL (Figure 4).

DISCUSSION

The aim of this study was to systematically review the comprehensive overview of literature data about Ti, Ti-Zr and Zr implants clinical outcomes, investigated in randomized controlled clinical trials, with a minimum follow-up of at least 6 months.

Ti implants have been used in dentistry for more than 40 years and are considered the gold standard for dental implants materials. Ti is known for its biocompatibility, strength, and resistance to corrosion. Zr implants, on the other hand, are relatively new to the market, and their use is rapidly increasing. The Zr implants have a white colour that blends with the teeth, and their biocompatibility makes them an excellent option for patients with metal allergies. Ti-Zr implants combine the best of both worlds by combining the biocompatibility of Zr and the strength of Ti.

The survival rate derives from the data of included articles ranged from 90.9% [20] to 91.2% [22] for Zr implants, for Ti implants articles ranged from 95.8% [20] up to 98.6% [22]. Ti-Zr implants SR was 100% at 1 year [23] follow-up in both groups. Payer et al. [21] presented an overall survival rate of 100% for Ti implants and 93.3% for Zr implants, but the results should be interpreted with caution due to the reduced sample of Ti (n = 15) and Zr (n = 16). However, a meta-analysis of the survival rate was not possible due to lack of information on confidence intervals and standard deviations in most of the included studies. A study carried out by Kohal et al. [24] involved implants that failed due to peri-implant infection accompanied by progressive bone resorption, which was all reported after the osseus healing period, and concluded that reduced osteoconductivity capacity of the material could not be appointed as a possible cause for increased bone loss observed.

MBL was evaluated as one of the primary outcomes, it was possible to verify that the results of the research had great similarities in both groups. However, most of the studies had a small follow-up period. Albrektsson and Isidor [25] suggested that implant success is valid if less than 1.5 mm of bone loss is seen during the first year after functional loading and thereafter a loss of < 0.2 mm annually. Thus, meaning that MBL is inevitable. Early MBL changes are a type of adaptive non-infective process that is influenced by surgical factors (surgical trauma, bone overheating, excessive implant tightening and crestal width) and prosthetic trauma (occlusal overload, type of implant design, microgap, abutment height and foreign body reaction to cement residue) [26-28]. A study done by Galindo-Moreno et al. [27] found that early high MBL changes of 0.44 mm at six months (after loading) were strongly associated with a subsequent increase of MBL changes of > 2 mm at 18 months. Hence, this six-month period may be used as an indicator for long term bone loss prognosis.

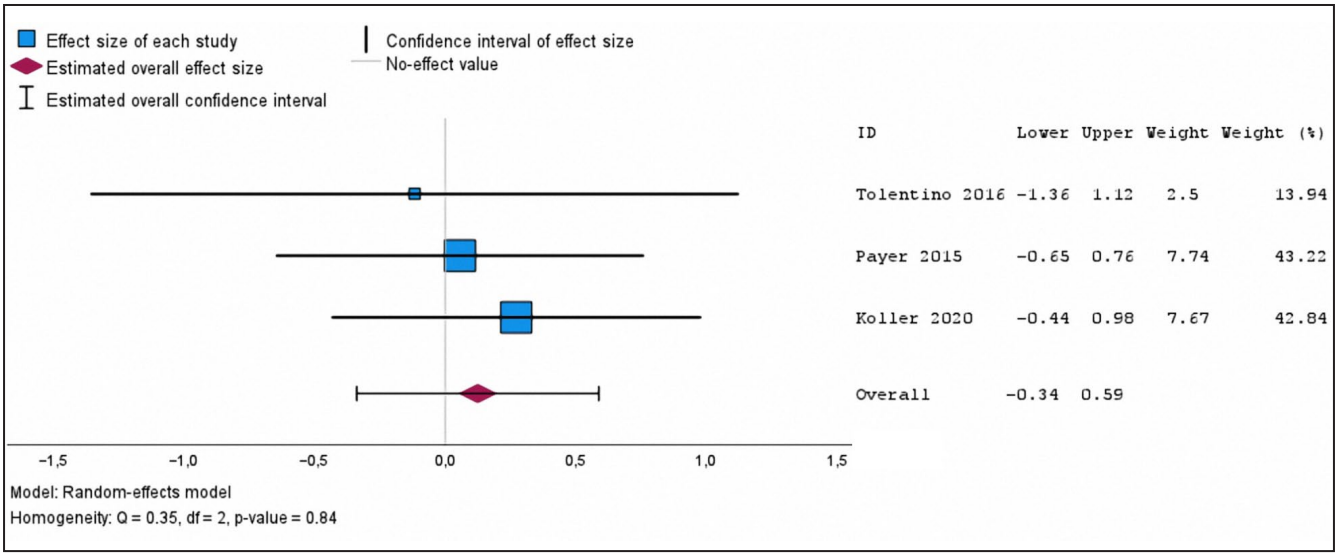

Figure 4. Forest plot marginal bone level.

With respect to the analysis of BoP, and PD results, only a handful of studies have provided data on these parameters. The available evidence is inconclusive as to whether Ti, Zr or Ti-Zr implants exhibit higher, lower, or similar BoP or PD levels, due to limited sample size of the studies.

Several studies have compared the clinical outcomes of Ti, Zr, and Ti-Zr implants. A systematic review and meta-analysis conducted by Pjetursson et al. [29] compared the clinical outcomes of Ti and Zr implants. The authors found that there was no significant difference in implant failure rates, marginal bone loss, or peri-implant infection rates between the two materials. However, Zr implants had a higher incidence of technical complications, such as implant fractures and chipping of the veneering material.

In contrast, a study sone by Gahlert et al. [30] compared the clinical outcomes of Ti and Ti-Zr implants. The authors found that Ti-Zr implants had a lower incidence of implant fracture and higher implant stability compared to Ti implants. However, the study also found that Ti-Zr implants had a higher incidence of technical complications, such as abutment fractures and screw loosening.

Overall, it is clear that Ti, Zr, and Ti-Zr implants all have their advantages and disadvantages. Ti implants are gold standard and have a long track record of success, while Zr implants offer excellent biocompatibility and a tooth-like colour. Ti-Zr implants combine the best of both worlds by offering biocompatibility and strength. When choosing implant material, it is essential to consider the patient is individual needs and preferences, as well as the surgeon is experience with each material. The choice of implant material should be made case-by-case basis, taking into considerations the patient's individual needs, preferences, and medical history. While the clinical outcomes of Ti, Zr, and Ti-Zr implants are comparable, each material has its unique advantages and disadvantages. Therefore, a thorough discussion between the patient and the surgeon is necessary to choose to most suitable implant material for the patient's specific case.

There are few limitations in this systematic review. One of them is that limited number of participants was enrolled in some of the included studies, and longer follow-up periods could be expected to provide long-term data. Studies had a follow-up period of only one year, which may not be sufficient to assess the long-term success of failure of dental implants. Talking about the heterogeneity of implant designs, the studies used different implant designs, including one-piece and two-piece implants, and implants made of different materials, such as Ti, Zr, and Ti-Zr alloys. This may limit the ability to draw conclusions about the relative effectiveness of each type of implants. Also talking about lack of standardized outcomes: the studies used different criteria to assess outcomes, such as marginal bone loss, implant stability, and peri-implant soft tissue health, which may make it difficult to compare and combine the results. Furthermore, it was not possible to include Ti-Zr implants as a separate group since it is made by a mixture of Ti and Zr and not only by one of those materials.

Even with the limitation of this study, the results suggest that Ti-Zr implants have better results in comparing to Ti and Zr implants, but in general there were no significant changes in both groups. To support the findings of this systematic review, further randomized controlled clinical studies with long-term evaluations and reduced risk of bias are imperative.

CONCLUSIONS

1. Dental implant survival rate seems to be lower in zirconia group.
2. Marginal bone loss had the best results in titanium-zirconium dental implants.
3. Titanium-zirconium implants had a better result than compared with titanium or zirconia for bleeding on probing.
4. No significant overall difference between zirconia, titanium, and titanium-zirconium implants could be observed in plaque control record.
5. Due to limited sample size it was not possible to obtain conclusion on probing depth parameter.

ACKNOWLEDGMENTS AND DISCLOSURE STATEMENTS

The authors report no conflict of interest related to this study.

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To cite this article:
Haimov E, Sarikov R, Haimov H, Juodzbalys G.
Differences in Titanium, Titanium-Zirconium, Zirconia Implants Treatment Outcomes: a Systematic Literature Review and Meta-Analysis
J Oral Maxillofac Res 2023;14(3):e1
URL: http://www.ejomr.org/JOMR/archives/2023/3/e1/v14n3e1.pdf
doi: 10.5037/jomr.2023.14301