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

SUMMARY

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

Materials and methods: In March 2023, a systematic electronic search through the PubMed (MEDLINE) and Cochrane library databases was performed to identify studies published between January 2013 and January 2023 containing a minimum of 10 patients per study comparing titanium, titanium-zirconium, and zirconia dental implants. Titanium, titanium-zirconium, and zirconia dental implant success was 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 titanium, 134 titanium-zirconium, and 199 zirconia) were evaluated, showing a survival rate of 97.7% for titanium, 98.6% for titanium-zirconium, and 93.8% for zirconia implants respectively. Still in the meta-analysis, there was no statistically significant difference between titanium, titanium-zirconium and zirconia implants in relation to marginal bone level ($p=0.84$).

Conclusions: when comparing with titanium and zirconia, the titanium-zirconium group demonstrated superior clinical outcomes.

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

INTRODUCTION

Since being introduced by Brånemark [1], dental implants made from titanium has revolutionized the field, offering a reliable, safe, and successful method for tooth replacement in various indications [2]. Primarily, the advantages of titanium 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 polycrystal (Y-TZP) has emerged in dentistry as an implant material due to its aesthetic, physical and mechanical properties [5]. Zirconia-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 titanium, zirconia is inferior in osseointegration and requires improvement by surface modification [8] although, few studies have demonstrated that zirconia 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 and plaque control record 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-zirconia and zirconium dental implants has different clinical outcomes in survival rate, marginal bone loss, bleeding on probing, plaque control record, and probing depth.

MATERIALS 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. Details are described in Figure 1.

The search of literature for this review was conducted between first of March 2022 and first of March 2023 which marks the end of the last search.

Focus question

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

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) database and Cochrane library.

Types of studies

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

Population

Adult healthy patients underwent oral rehabilitation with titanium, titanium-zirconium, and zirconia dental implants.

Literature search strategy

According to the PRISMA guidelines [11] 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 2013 to January 2023.

Inclusion criteria for the selection

Investigations were considered eligible when they met the following criteria:

- Clinical studies published in English between January 2013 and January 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, that evaluated the clinical outcome of titanium, titanium-zirconium, zirconia dental implants.

Exclusion criteria

- 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), bleeding on probing (BOP), probing depth (PD), and plaque control record (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 were 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 [12] 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 2.79 reference management software (www.mendeley.com) was used for article management. The meta-analysis was conducted in SPSS software version 29.0 Review. The level of P-value was set at <0.05.

RESULTS

Study selection and exclusion

The search delivered 1361 search results (Figure 1). Inter-rater reliability Kappa of 0.88 was achieved. 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. Articles that did not meet the inclusion and

exclusion criteria were filtered as follows: studies conducted on species other than human (n=10); clinical studies on patients with < 10 patients (n=5); literature review (n=5); lack of control or test group (n=5). A total of 25 articles were ultimately reviewed in full.

A total of 10 studies were included in this review: all the studies were related to outcome associated to titanium, titanium-zirconium and zirconia implants (Figure 1 and Table 2). The data were included on 301 patients with 637 implants (304 titanium, 199 zirconia and 134 titanium-zirconium).

Assessment of risk of bias

The risk of bias was evaluated, and bias was observed in all studies. The highest amount of bias was observed in Osman et al. [19] study (two minus boxes and one question-mark), while Ioannidis et al. [16] had only one question-mark box. Müller et al. [18] and Koller et al. [17] showed only one question-mark box, while Tolentino et al. [22] and Bienz et al. [14] presented only one minus box and one question-mark box, Benic et al.[13], Hassouna et al. [15], Siddiqi et al. [21] and Payer et al. [20] showed only plus boxes so no bias was found. 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 Table 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 [13,15,16] 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, 199 were Zr and 134 were TZ implants (**Table 4**). The amount of implant lost during the follow-up period was as follows: 22 Ti (3.4%), 45 Zr (7.1%), and 1 TZ (0.2%) implant. Four studies [16–18,20] used two-piece implant, another four studies [13,15,19,21] used one-piece implant, [14,22] did not report the type of setting used.

Regarding the implant system, four studies [13,14,16,22] used Straumann (Basel, Switzerland). implants, other three studies [17,18,20] used Ziterion® (Ziterion GmbH, Uffenheim, Germany) implants, while [19,21] used Southern implants, [15] did not mention the company of the implants.

Nine of the ten included studies reported the number of failed implants [13–15,17–22], also nine studies [13,15–22] reported about MBL level. BOP was reported by 6 studies [13,14,16,17,20,22] and PD by five [14–16,21,22] the minimum follow-up period of the outcomes variables (SR, MBL, BOP, PD and PCR) was six months and the maximum follow-up period was eighty months. Eight of the studies [13–17,20–22] proceeded with a flap technique, while one study [19] used flapless approach. The patients received a preoperative antibiotics prophylaxis in five of the studies [13,15–17,21] and five studies [14–17,20] reported about prescription of postoperative antibiotics for the patients. A postoperative instruction on chlorhexidine rinse was made in six of the clinical trials [13–16,21,22] , while only three studies followed a preoperative mouth rinse protocol [14,15,21].

Implant features

Implants were classified according to their diameter and length. For the Ti implants Hassouna et al. [15] used 12 mm implant length, while [17,20] used 11.5 mm implants length, other three studies [13,14,16] used 8 mm in length, Müller et al. [18] and Osman et al. [19] used three types of length (8, 10, 11.5 mm).

For the Zr and Tz implants Hassouna et al. used [15] implant length of 12 mm, three other studies [13,14,16] used implant length of 8 mm, while Koller et al. [17] and Payer et al. [20] used three types of length (10 mm, 11.5 mm, 13 mm), Müller et al. [18] and Osman et al. [19] used also three types of implant length (8 mm, 10 mm, 10.5 mm), two another studies [21,22] did not mentioned implant length.

Regarding the diameter, Koller et al. [17] reported regular diameter implants for both Ti and Zr implants. Two studies [14,20] used a regular diameter (4.1 mm) for both Ti and Zr implants, Benic et al. [13] 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 TZ implants, Hassouna et al. [15] used a regular diameter (4.5 mm) for Ti implants and narrow diameter (3.6 mm) for Zr implants, two studies [19,21] used reported the utilization of regular and wide diameter for Zr and Ti implants (3.8 mm to 5.0 mm), Müller et al. [18] and Tolentino et al. [22] placed a narrow diameter (3.3 mm) for the both implants.

Survival rate (SR)

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

2.3.3 Marginal bone loss (MBL)

For MBL parameter nine of the included clinical trials analysed the MBL measurements. Koller et al. [17], found that zirconia implants were associated with a mean MBL of 1.51 mm (SD: 0.68; median: 1.48) at 30 months and 1.38 mm (SD: 0.81; median: 1.27) at 80 months (Table 5). The corresponding values for titanium implants were 0.92 mm (SD: 0.72; median: 1.03) and 1.17 mm (SD: 0.73; median: 1.05). No significant intragroup difference from 30 to 80 months was noted for the zirconia or titanium group ($p > 0.05$). Ioannidis et al. [16] From the 1-year to the 3-year examination, median change in mean MBL measured 0.01 mm (mean: 0.14; SD 0.59 mm) for the Ti implants and 0.04 mm (mean: 0.05; SD: 0.41 mm) for the Ti-Zr implants. The difference between the groups was not statistically significant ($p>0.05$). Payer et al. [20] with follow-ups of 6, 12, 18, 24 months registered mean MBL measurements for Zr implants yielded 0.67 mm (SD 0.95; ME 0.29), 1.16 mm (SD 1.01; ME 0.8), 1.2 mm (SD 0.76; ME 1.11) and 1.48 mm (SD 1.05; ME 1.1), for Ti implants mean marginal bone level was 0.16 mm (SD 0.24; ME 0.0), 0.4 mm (SD 0.38; ME 0.34), 0.88 mm (SD 0.56; ME 0.88), 1.15 mm (SD 0.73; ME 1.12) and 1.43 mm (SD 0.67; ME 1.1) ($P<0.001$). Muller et al. [18] showed no significant differences in marginal bone level between the Ti-Zr and the Ti group, assessed 60 months after implant placement ($p>0.05$). The mean change in the Ti-Zr group was -0.60 ± 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. [22] after 1 year of follow-up registered -0.35 ± 0.24 mm of MBL for Ti implants and for TZ 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 -0.42 ± 0.40 for Zr implants. Siddiqi et al. [21] 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. [13] had -0.46 ± 0.50 mm MBL for Ti implants and -0.50 ± 0.63 for TZ implants, Hassouna et al. [15] had -0.50 ± 0.63 mm MBL for Ti implants and -1.77 ± 0.41 for Zr implants. No significant difference was found between the different groups at follow-up times (**Table 5**).

Bleeding on probing (BOP)

Only six studies showed information about BOP (**Table 5**). For Payer et al. [20] Evaluation of bleeding on probing revealed for zirconia implants 9.1% (4.34; ME 9.2) after 24 months and 7.4% (3.39; ME 7.0) after 24 months for titanium implants. Tolentino et al. [22] after 1 year of loading revealed the same number 10% for both titanium and titanium zirconium implants. Ioannidis et al. [16] after 3 years follow-up showed for Ti implants 20 ± 19.1 % and 13.8 ± 17.9 % for TZ implants ($p>0.05$), Benic et al. [13] registered after 1 year of follow-up 12.5 ± 12.9 % for Ti implants and 12.7 ± 19.1 % for TZ implants ($p>0.683$), Koller et al. [17] 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. [14] showed 32.5 ± 27.8 % for Ti implants and 21.7 ± 23.6 % for Zr implants ($p<0.05$). No significant overall difference between zirconia and titanium implants could be observed.

Probing depth (PD)

Only 5 studies showed information about this parameter (Table 5). Ioannidis et al. [16] registered 2.6 (SD;0.8) mm for Ti-Zr implants and 2.9 (SD;0.8) mm for Ti implants after 3 years follow-up ($p>0.05$). For the 1-year follow-up, Tolentino et al. [22] showed same number 3.1 mm for both implants ($p>0.05$), Siddiqi et al. [21] wrote 1.59 ± 0.50 mm for Ti implants and 2.2 ± 0.61 mm for Zr implants. Bienz et al. [14] 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. [15] that reported 3.5 ± 0.6 mm for Ti implants and 3.3 ± 0.5 for Zr implants ($p<0.01$).

Plaque control record (PCR)

Four of the included clinical trials analysed the PCR (Table 4) [13,14,16,17] One of the studies reported two follow-up periods of 30 months and 80 months [17] 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 15.20 ± 15.58% for Ti implants and 11.07 ± 8.11 % for Zr implants. Ioannidis et al. [16] with one follow-up period after 3 years registered 10.0 ± 16.4 % for Ti-Zr implants and 7.7 ± 11.9 % for Ti implants ($p>0.05$). Another study [13] with 1 year follow-up reports plaque control record of 6.2 ± 12.0 % for Ti implants and 3.9 ± 9.3% for Ti-Zr implants ($p>0.05$), the last study [14] with the lowest period

of six months follow-up reported an overall of 75.0 ± 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 outcome measures. However, the included studies of the meta-analysis revealed substantial variations in study design, i.e., gender effects, marginal bone loss, bleeding on probing. 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 heterogenous, 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).

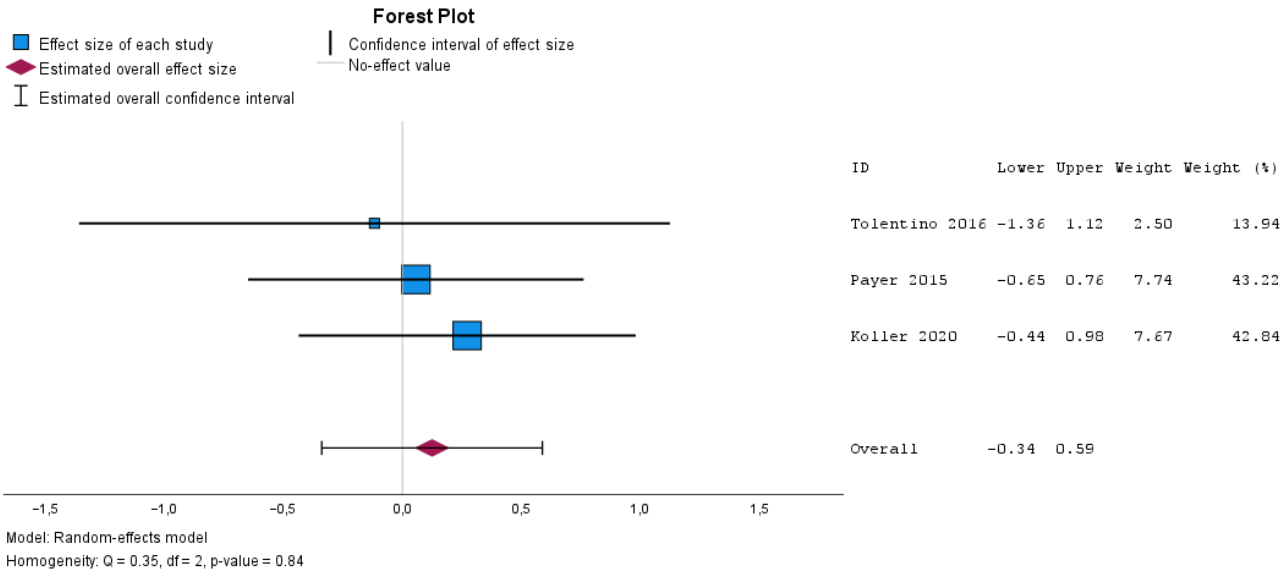


Fig. 4. Forest plot marginal bone level.

DISCUSSION

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

Titanium 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 zirconia implants have a white colour that blends with the teeth, and their biocompatibility makes them an excellent option for patients with metal allergies. TZ 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% [19] to 91.2% [21] for Zr implants, for Ti implants articles ranged from 95.8 % [19] up to 98.6 % [21]. TZ implants SR was 100% at 1 year [22] follow-up in both groups. Payer et al. [20] presented an overall survival rate of 93.3% for zirconia implants and 100% for titanium implants but the results should be interpreted with caution due to the reduced sample of Zr (n=16) and Ti (n=15). 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. [23] 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 [24] 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) [25–27]. A study done by Galindo-Moreno et al. [26] 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.

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 TZ 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 TZ implants. A systematic review and meta-analysis conducted by Pjetursson et al. [28] 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, zirconia 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. [29] compared the clinical outcomes of Ti and TZ implants. The authors found that TZ implants had a lower incidence of implant fracture and higher implant stability compared to Ti implants. However, the study also found that TZ implants had a higher incidence of technical complications, such as abutment fractures and screw loosening.

Overall, it is clear that Ti, Zr, and TZ implants all have their advantages and disadvantages. Ti implants are gold standard and have a long track record of success, while zirconia implants offer excellent biocompatibility and a tooth-like colour. TZ 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 TZ 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 were 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 TZ 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 TZ 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 titanium-zirconium implants have better results in comparing to titanium and zirconia implants, but in general there was 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 Zr group.
2. Marginal bone loss had the best results in TZ dental implants.
3. TZ implants had a better result than compared with Ti or Zr for BoP.
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 assessed in was not possible to obtain conclusion on PD parameter.

ACKNOWLEDGMENTS AND DISCLOSURE STATEMENTS

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

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 success 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?

Table 2. Description of studies included in the review.

Author	**Year**	**Follow-up**	**Design**	**Population**	**Patients (n)**	**Gender**	**Control and test group**
Benic et al. [13]	2013	1 year	Prospective randomized clinical trial	patients in need of an implant-supported crown	40	NR	Control group: a Ti 4.1 mm

							diameter implant Test group: a Ti-Zr 3.3 mm diameter implant
Bienz et al. [14]	2021	6 months	Prospective randomized clinical trial	Prerequisite were two missing adjacent teeth	42	8M/12F	Test group: Ti implants control group: Zr implants
Hassouna et al. [15]	2022	5 years	Prospective cohort study	Replacement of a single-tooth in the maxillary premolar area.	28	NR	Control group: one-piece titanium implant. Test group: one-piece zirconia implant
Ioannidis et al.[16]	2015	3 years	Prospective randomized clinical trial	patients in need of an implant-supported crown	40	NR	Control group: a Ti 4.1 mm diameter implant Test group: Ti-Zr 3.3mm

							diameter implant
Koller et al. [17]	2020	6.5 years	Prospective randomized clinical trial	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	13M/9F	Control group: two-piece implants made of yttria-stabilized zirconia Test group: standard two-piece titanium implants
Müller et al. [18]	2015	5 years	Prospective randomized clinical trial	Patients who had completed the core study were invited to participate in the follow-up study to collect long-term data	47	24M/23F	Control group: Ti implants Test group: Ti-Zr implants
Osman et al. [19]	2014	1 year	Prospective randomized clinical trial	Patients with functional problems in their use of complete dentures	24	15M/4F	Control group: one-piece titanium implant Test group: one-piece

							zirconia implant
Payer et al. [20]	2015	2 years	Prospective randomized clinical trial	Patients providing tooth gaps up to three missing units with a sufficient amount of horizontal and vertical bone for the placement of implants	22	13M/9F	Control group: two-piece standard titanium implants Test group: two-piece yttria-stabilized zirconia implants
Siddiqi et al. [21]	2015	1 year	Prospective randomized clinical trial	Patients involved surgical and prosthodontic rehabilitation of 24 completely edentulous participants with implant overdentures	24	15M/4F	Control group: implants were made from titanium Test group: Zr implants were used
Tolentino et al. [22]	2016	1 year	Prospective randomized clinical trial	patients for single-unit prosthetic rehabilitation in contra lateral molar sites of the mandible	12	4M/8F	Control group: cpTi implants Test group: Ti-Zr implants

				were included in the study			

NR = not reported, Ti = titanium, Zr = zirconia.

Table 3. Assessment of the risk of bias.

	Random sequence generation	**Allocation concealment**	**Blinding (participants and personnel)**	**Blinding (outcome assessment)**	**Incomplete outcome data**	**Selective reporting**	**Other bias**
Osman et al. [19]	+	**-**	**-**	***?***	+	+	+
Ioannidis et al. [16]	+	+	**-**	+	+	+	+
Müller et al. [18]	+	+	+	***?***	+	+	+
Payer et al. [20]	+	+	+	+	+	+	+
Koller et al. [17]	+	+	***?***	+	+	+	+
Tolentino et al. [22]	+	***?***	**-**	+	+	+	+
Siddiqi et al. [21]	+	+	+	+	+	+	+
Benic et al. [13]	+	+	+	+	+	+	+
Bienz et al.[14]	+	+	***?***	**-**	+	+	+
Hassouna et al. [15]	+	+	+	+	+	+	+

Table 4. Studies' characteristics and detailing.

Author	Mean age	Dropout	Titanium implant (n)	Zirconia implant (n)	Implant system	Implants lost	1 or 2 pieces
Benic et al. [13]	NR	2	20	20 (TZ)	Straumann	0	1
Bienz et al. [14]	55	2	42	42 (TZ)	Straumann	0	NR
Hassouna et al. [15]	NR	0	14	140	NR	0	1
Ioannidis et al. [16]	NR	NR	20	20 (Zr)	Straumann	NR	2
Koller et al. [17]	46± 26	0	15	16 (Zr)	Ziterion® (Vario T; Ziterion)	1 Ti / 2 Zr	2
Müller et al. [18]	72±8	16	47	47 (Zr)	Ziterion® (Vario T; Ziterion)	1 Ti/1 TZ	2
Osman et al. [19]	62± 17	5	56	73 (Zr)	Southern implants	10Ti/21 Zr	1
Payer et al. [20]	46± 26	0	15	16 (Zr)	Ziterion® (Vario T; Ziterion)	1 Zr	2
Siddiqi et al. [21]	62± 16	3	70	80 (Zr)	Southern implants	10Ti/21 Zr	1
Tolentino et al. [22]	43.3± 6	0	5	5 (TZ)	Straumann	0	NR

NR=not reported, Ti = titanium, Zr = zirconia, TZ = titanium-zirconium.

Table 5. Clinical data of the included studies.

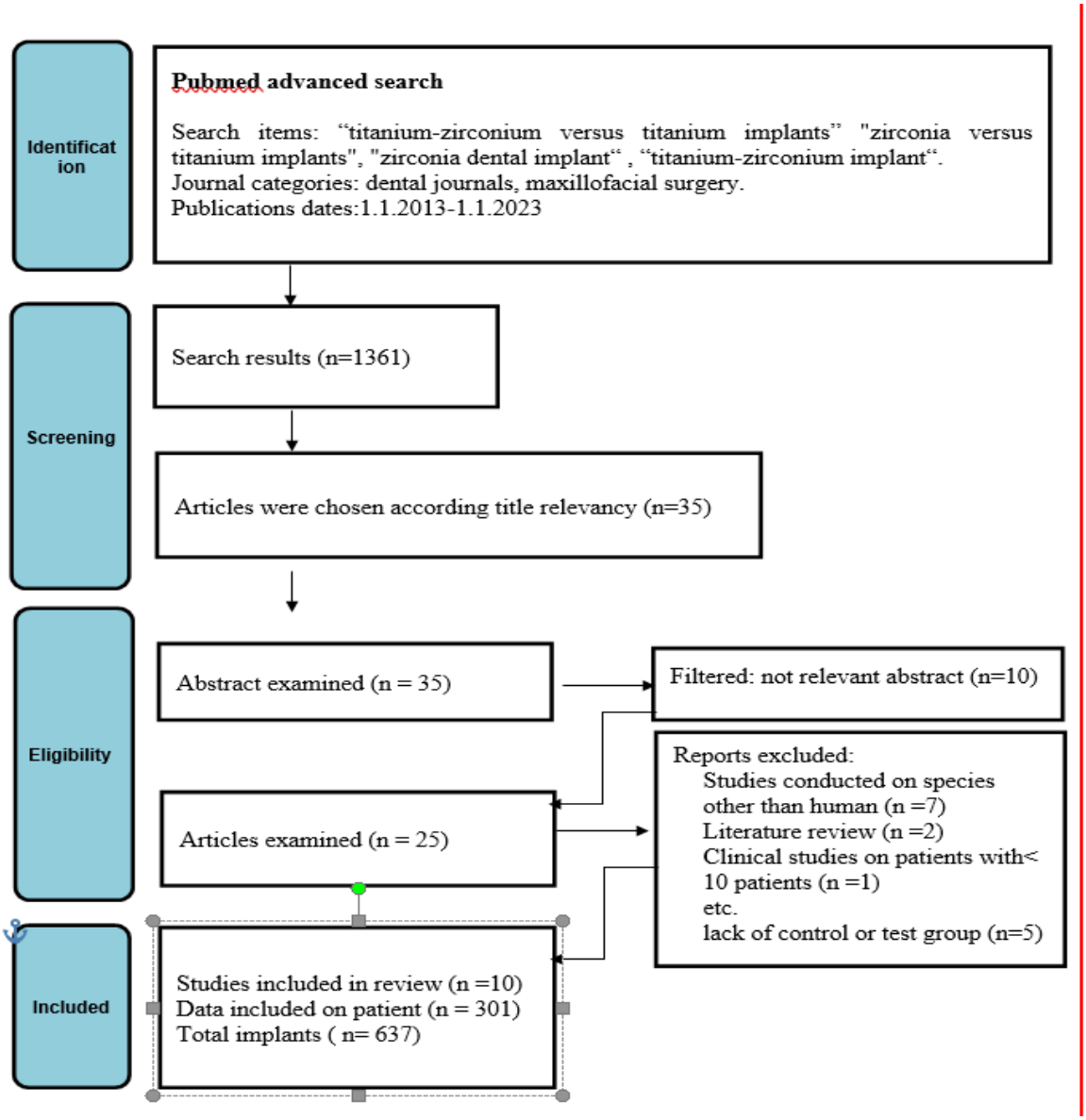
Study	Follow-up (Y)	SR Ti (%)	SR Zr (%)	MBL Ti (mm)	MBL Zr (mm)	BOP Ti (%)	BOP Zr (%)	PD Ti (mm)	PD Zr (mm)	PCR Ti (%)	PCR Zr (%)
Benic et al. [13]	1 year	100	100 (TZ)	-0.46± 0.50	-0.50± 0.63(TZ)	12.5± 12.9	12.7± 19.1 (TZ)	NR	NR	6.2± 12.0	3.9 ± 9.3(TZ)
Bienz et al. [14]	6 months	100	100	NR	NR	32.5± 27.8	21.7± 23.6	2.6± 0.4	2.4± 0.4	75.0± 29.4	68.3± 31.9
Hassouna et al. [15]	5 years	100	100	-1.8± 0.24	-1.77± 0.41	NR	NR	3.5± 0.6	3.3± 0.5	NR	NR
Ioannidis et al. [16]	3 years	97.3	98.7 (TZ)	-0.38± 0.55	-0.50± 0.90 (TZ)	20± 19.1	13.8± 17.9 (TZ)	2.9± 0.8	2.6± 0.8 (TZ)	7.7± 11.9	10± 16.4 (TZ)
Koller et al. [17]	6.5 years	93.3	87.5	-1.17± 0.73	1.38± 0.81	12.6± 7.6	16.4± 6.16	NR	NR	15.2± 15.58	11.07± 8.11
Müller et al. [18]	5 years	92.6	95.8(TZ)	-0.61± 0.83	-0.60± 0.69(TZ)	NR	NR	NR	NR	NR	NR
Osman et al. [19]	1 year	95.8	90.9	-0.18± 0.47	-0.42± 0.40	NR	NR	NR	NR	NR	NR
Payer et al. [20]	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. [21]	1 year	98.6	91.2	-0.125 ±0.34	-0.25± 0.23	NR	NR	1.59± 0.50	2.2± 0.61	NR	NR
Tolentino et al. [22]	1 year	100	100 (TZ)	-0.35± 0.24	-0.32± 0.27 (TZ)	10	10 (TZ)	3.051	3.1 (TZ)	NR	NR

SR = survival rate, MBL = marginal bone loss, BoP = bleeding on probing, PD = probing depth, PCR = Plaque control record, NR = nor reported, Y = years.

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. [13]	Flap	Yes	No	No	Yes
Bienz et al. [14]	Flap	No	Yes	Yes	Yes
Hassouna et al. [15]	Flap	Yes	Yes	Yes	Yes
Ioannidis et al. [16]	Flap	Yes	No	Yes	Yes
Koller et al. [17]	Flap	Yes	No	Yes	No
Müller et al. [18]	NR	No	No	No	No
Osman et al. [19]	Flapless	No	No	No	No
Payer et al. [20]	Flap	No	No	Yes	No
Siddiqi et al. [21]	Flap	Yes	Yes	No	Yes
Tolentino et al. [22]	Flap	No	No	No	Yes

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



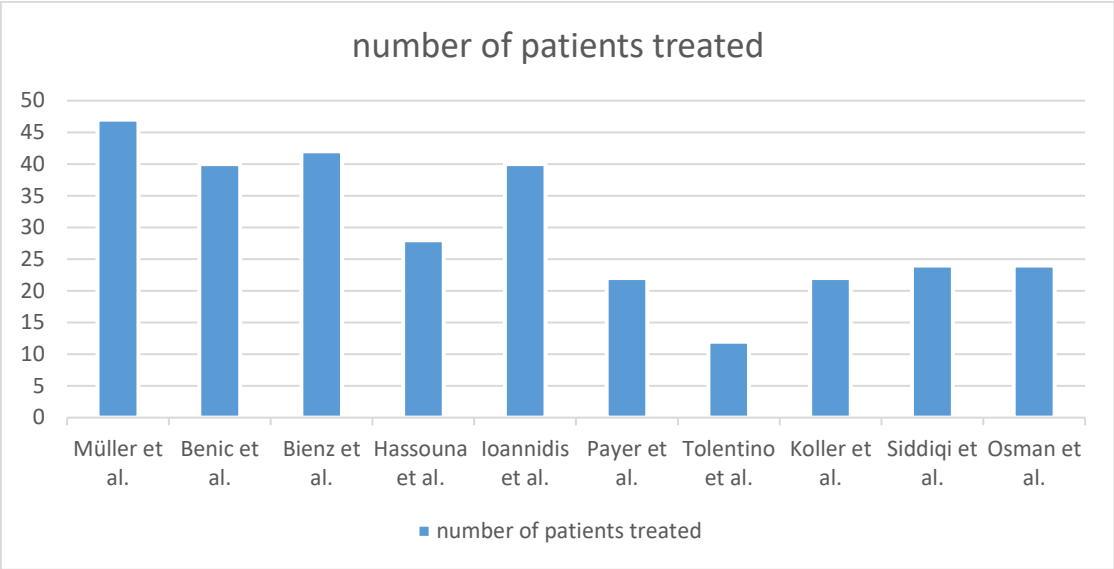


Fig. 2. Number of patients treated.

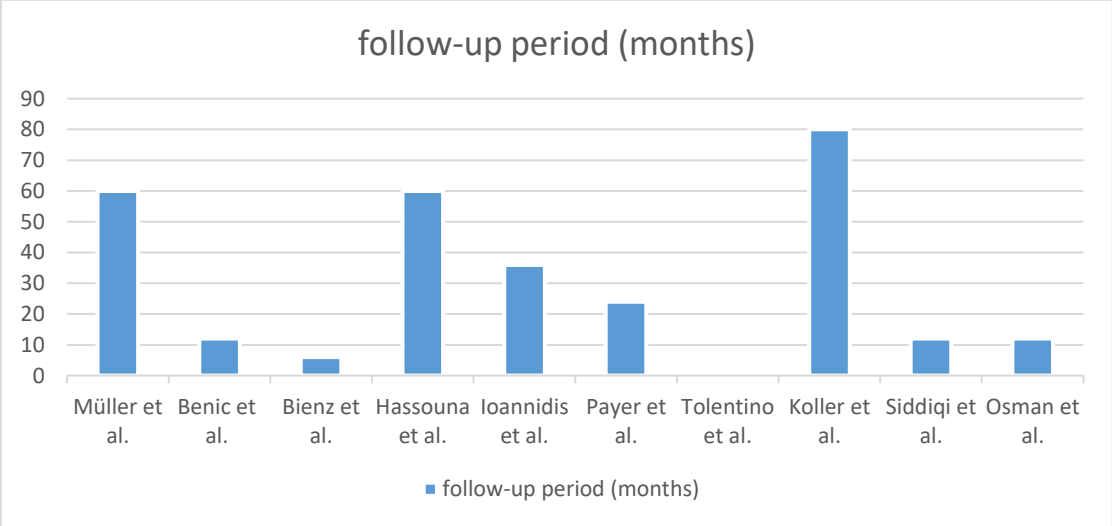


Fig. 3. Follow-up period.

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