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Review

A systematic review and meta-analysis on the clinical outcome of zirconia implant–restoration complex

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ABSTRACT

Purpose: This systematic review evaluates the clinical outcome of zirconia implant-associated survival and success rates, marginal bone loss, and implant–restoration complex integrity.
Study selection: Using the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines, studies including ≥ 10 patients restored with zirconia implants supporting single crowns (SCs) or fixed dental prostheses (FDPs) prior to January 2017 were identified. Primary outcomes were survival rates and marginal bone loss around one and two-piece zirconia implants and the associated implant–restoration complex integrity.
Results: 1349 studies were selected; after duplicate removal and title screening, 36 remained for full-text screening. 17 studies met the inclusion criteria: 2 randomized controlled clinical studies, 11 prospective clinical studies and 4 retrospective studies. In total, 1704 implants from 1002 patients were evaluated, including 1521 one-piece and 183 two-piece zirconia implants with follow-up between 1 and 7 years. The mean survival rate was 95 % (95 % CI 91–97 %). The overall mean marginal bone loss was 0.98 mm (95 % CI 0.79–1.18); the mean marginal bone loss after 1 year was 0.89 mm (95 % CI 0.60–1.18). No meta-analysis regarding prosthetic outcomes was possible.
Conclusions: Survival and marginal bone loss values after one year for one-piece zirconia implants are acceptable, but long-term studies are required to support their clinical use. No particular restoration material can be recommended; this decision is apparently based on clinicians' preferences.
Results from two-piece implants do not provide sufficient data to support their clinical use and no abutment or cementing materials for two-piece zirconia implants can be recommended.

1. Introduction

The use of dental implants for the replacement of missing teeth is a well-documented treatment modality. The procedure is facilitated via postoperative osseointegration, defined as a direct functional and structural connection between living bone and the surface of a load-bearing implant [1].

For more than 40 years, medical-grade commercially pure titanium or titanium alloy has been the gold standard material for the fabrication of dental implants. Studies investigating the clinical outcome of titanium implants showed survival rates of 97.2 % after 5 years for single crown-supporting implants, 96.4 % after 5 years for implants supporting fixed dental prostheses (FDPs) [2] and 96.86 % after 10 years for implants supporting FDPs in edentulous jaws [3].

Despite the clinical success of implants, biological complications, namely peri-implant diseases [4–6] implant loss, can and do occur. In addition to these complications, a number of studies reported that titanium can cause hypersensitivity reactions [7–12]. Hypersensitivity to biomaterials in the oral cavity typically manifests as facial eczema, non-keratinized edematous hyperplastic gingiva, vague pain, skin rashes, or in some cases, implant loss [8,11]. A clinical study involving 1500 patients documented the prevalence of titanium allergy as low as 0.6 % [13]. Despite growing concerns about its biocompatibility, the current evidence for hypersensitivity or allergy to titanium remains very weak: in fact, reports relate the observed hypersensitivity to impurities in the implant material and not to the titanium itself [14]. Interestingly, the majority of patients hypersensitive to titanium implants also exhibited hypersensitivity to other materials, namely chromium and nickel [13]. Therefore, the potential

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contraindication of titanium implants due to the possibility of hypersensitivity seems to be limited to a very small group of patients [10].

In addition to biological complications, technical complications in titanium implants, such as veneering material fracture, screw loosening and fracture, and implant fracture, have been reported. In a systematic review, the most frequent complications over a 5-year observation period of titanium implants were fractures of the veneering material (13.5%), loss of access hole restoration (5.4%), abutment or screw loosening (5.3%), and retention loss of cemented FDPs (4.7%) [5]. In addition, esthetic complications are also present in titanium implants. For example, the presence of a thin gingival biotype around a titanium implant may lead to tissue discoloration due to the visible, dull grayish background color of the titanium [15]. In the anterior visible region, especially with a high lip line, such a discoloration is considered a disadvantage of titanium that jeopardizes esthetics if no interventions are performed to mask it.

The biological and technical concerns for titanium implants, along with patient-specific requests for metal-free treatment, have pushed the search for alternative implant materials. Among these, zirconia has been undergoing extensive experimental and clinical research to evaluate its feasibility as an alternative implant material that guarantees a successful long-term outcome.

Zirconia has a number of favorable characteristics, such as high flexural strength (900–1200 MPa) and hardness [16]. Also, several animal investigations have demonstrated its biocompatibility as an implant material [17,18]. Zirconia also presents a significantly reduced plaque affinity, which leads to a reduced risk of inflammatory reactions around soft tissues [17,19]. For these reasons, a growing number of (mostly European) implant manufacturers are introducing zirconia implants. As previously described in part I of this review, zirconia implants differ in their material composition, surface treatment, and implant and component design. Two zirconia-based materials commonly evaluated in clinical studies are yttria-stabilized tetragonal zirconia (YTZ) and alumina-stabilized tetragonal zirconia (ATZ) [16,20,21].

In addition to planning and selection of the implant material, surface treatments are often performed to obtain a rough surface, which has been shown to improve the bone-to-implant contact and thus the osseointegration [22]. The most frequently used commercially available surface modifications on zirconia implants are sandblasting, acid-etching, and laser peening [22]. In certain instances, surface treatments such as sandblasting and acid etching are combined in order to further improve the bone-to-implant contact capacity (e.g. Zeramex, Dentalpoint, Spreitenbach and Pure, Straumann, Basel).

As a final variable potentially affecting clinical outcome, zirconia implant design can be classified into one of two types: one-piece implants, which consist of an implant and abutment as a single unit and two-piece implants, which do not include the abutment on the same unit. The latter offers the possibility to screw or cement the abutment in place. Previously published clinical studies include only cemented abutments and report lower implant strength and more frequent technical complications than one-piece implants [23].

Currently, more data is available for one-piece implants, which show improved mechanical properties relative to two-piece implants [24].

Regarding the material and restorative option (e.g., single crowns (SCs) or fixed dental prostheses (FDPs)) used for zirconia implants, no specific recommendations based on observed survival rates have been proposed. These remain open questions to be clarified by clinicians.

As discussed in part I of this review, preclinical and animal studies on zirconia implants have demonstrated comparable results to those for titanium implants regarding biocompatibility, osseointegration capacity and soft tissue response [25]. Hence, zirconia implants may be considered a potential alternative to titanium implants. In order to fully evaluate clinical performance and therefore, the feasibility of recommending zirconia implants. Clinical studies are the ideal tool to provide clinicians with important information when considering zirconia implants [6,26]. Therefore, the aim of this systematic review was to evaluate the clinical outcome of zirconia implants and their associated implant–restoration complexes.

2. Materials and methods

The aim of this systematic review was to evaluate the clinical outcome of zirconia implants and their associated implant–restoration complexes. For that reason, the focused question of this systematic was: How is the clinical outcome of zirconia one- and two-piece implants and their associated implant–restoration complexes?

This systematic review utilized a strategy adapted from the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Fig. 1) [27,28] and the patients, intervention, comparison, outcomes (PICO) method. This review started with an electronic Medline (PubMed) search for clinical studies about zirconia implants published in the English-language dental literature from 1990 to January 2017. The search was conducted with the following keywords: "Zirconia Implants"; "Clinical study"; "Survival"; "Success"; and "Prosthetic outcomes".

Hand-searching of the bibliographies of all full-text articles and related reviews selected from the electronic search was also performed for the following journals: *International Journal of Maxillofacial Implants; Clinical Implant Dentistry and Related Research; Clinical Oral Implants Research; European Journal of Implantology; Implant dentistry; International Journal of Oral and Maxillofacial Surgery; International journal of Periodontics & Restorative Dentistry; International Journal of Prosthodontics; Journal*

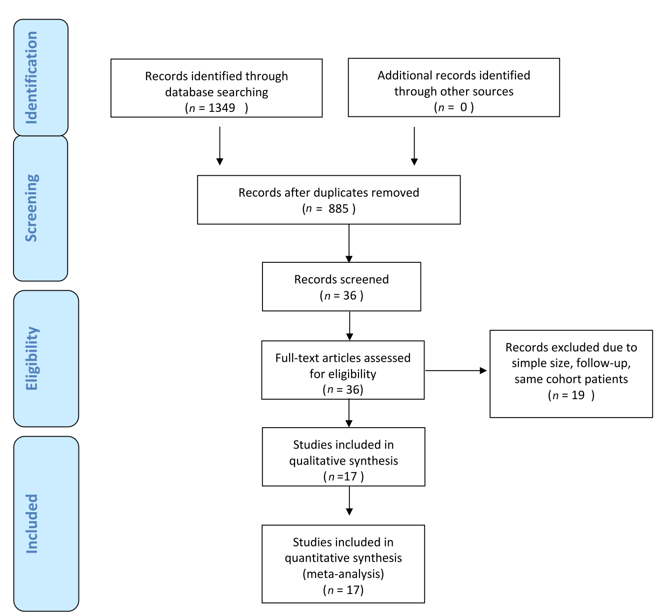

Fig. 1. Search strategy of the clinical studies.

of Periodontology; Journal of Periodontology; Journal of Prosthetic Dentistry; Journal of Prosthodontics; Journal of Oral Surgery; Quintessence International; Journal of Prosthodontic Research; Periodontology 2000.

2.1. Study selection

Titles were screened by two independent reviewers (MH, HN) for possible inclusion in the review. Following this, abstracts of all titles agreed on by both authors were obtained. Based on the selection of abstracts, articles were then obtained for full-text analysis. Full-text of selected studies was performed for inclusion criteria. Disagreements were resolved by discussion.

2.2. Quality assessment

The assessment of the quality of the included studies was performed by two reviewers (MH, HN). The assessment was carried out according to the design, level of evidence, extent of clinical and radiographic examinations, adjustment for alternative surgical protocols, completeness of follow-up, statistical analysis and industry funding (Table 1). A similar approach for quality assessment was previously described [29]. The evidence level of the studies was extracted from the Agency for Health Care Policy and Research (1993).

2.3. Inclusion and exclusion criteria

Inclusion criteria

- Randomized controlled clinical trials, controlled clinical trials.
- Prospective and retrospective clinical studies as well as prospective case series.
- Follow-up of at least 1 year after prosthetic delivery.
- Human studies with a minimum of 10 subjects.
- Patients examined clinically at the follow-up visit.
- Studies reported in the English language and published in a dental journal.
- Report of survival and/or success rates.
- Implants with SCs and FDPs.

Exclusion criteria

- Pilot studies, case reports, animal studies.
- Less than 10 subjects included in the follow-up.
- Follow-up time less than 1 year after implant placement.

2.4. Data extraction

Information was extracted regarding study design, journal, implant type (one-piece, two-piece) system, patient and implant numbers, follow-up time, biological complications, technical complications and lost implants and prosthetic restorations. In cases for which more specific information was required, the authors were contacted.

The population, intervention, comparisons, outcomes (PICO) format was used to define a focused clinical question, which in this analysis was: how do zirconia implants and related prosthetic rehabilitations perform after at least 1 year of clinical function?

The PICO criteria were as follows:

- Population: patients treated with zirconia implants.
- Intervention: zirconia implants and prosthetic rehabilitations.
- Comparison: biological and technical parameters related to one- and two-piece zirconia implants, as well as prosthetic rehabilitations after a minimum of 1 year follow-up.
- Outcome: clinical outcome "survival" of zirconia implants and the zirconia implant–restoration complex.

2.5. Statistical analysis

We used the random effects model using the DerSimonian–Laird estimator for heterogeneity variance. Cochrane's Q and Higgins's I2 statistics were used to measure the heterogeneity of the included studies. To illustrate the results, forest plots including the fixed effect estimate for comparison were generated. For all analyses, the R package meta was used [43].

3. Results

3.1. Overall results

A total of 1349 studies were identified in the literature. After duplicate removal, 885 were left. Studies were then screened by title

Table 1
Quality asessment of the included studies.

Author	Study	Evidence Level Accordirng to Centre for Evidence-Based Medicine	Detaile clinical exam	RX. Quality and interpretation	Adjustment for different surgical and loading protocols	Completeness of follow up	Statistical analysis	Industry funding	Risk of bias
Blaschke et al. [19]	Retrospective	III	No	No	No	Yes	No	Yes	High
Becker et al. [30]	Prospective	III	Yes	No	Yes	Yes	Yes	Yes	Moderate
Borgonovo et al. [31]	Retrospective	III	Yes	Yes	Unclear	Yes	Yes	No	Low
Brüll et al. [32]	Retrospective	III	Yes	Yes	No	Yes	Yes	Yes	Moderate
Cannizzaro et al. [33]	RCT	Ib	No	Yes	Yes	Yes	Yes	Yes	Low
Cionca et al. [34]	Prospective	III	Yes	No	Yes	Yes	Yes	Yes	Low
Grassi et al. [35]	Prospective	III	Yes	Yes	Yes	Yes	Yes	Yes	Low
Jung et al. [36]	RCT	Ib	Yes	Yes	Yes	Yes	Yes	Yes	Low
Kohal et al. [16]	Prospective	III	Yes	Yes	No	Yes	Yes	Yes	Moderate
Osman et al. [37]	RCT	1b	No	Yes	No	Yes	Yes	Unclear	Moderate
Payer et al. [38]	RCT	1b	Yes	Yes	Yes	Yes	Yes	Yes	Low
Roehling et al. [39]	Retrospective	III	Yes	Yes	Yes	Yes	Yes	Yes	Low
Spies et al. [20]	Prospective	III	Yes	Yes	Yes	Yes	Yes	Yes	Low
Oliva et al. [22]	Prospective	III	No	No	Yes	Yes	Yes	Yes	Moderate
Kohal et al. [40]	Prospective	III	Yes	Yes	No	Yes	Yes	Yes	Moderate
Payer et al. [41]	Prospective	III	Yes	Yes	Yes	Yes	Yes	Yes	Low
Pirker et al. [42]	Prospective	III	Yes	No	No	Yes	Yes	Unclear	Moderate

Table 2
Reasons for exclusion.

Author	Title	Reason for exclusion
Borgonovo et al. [44]	Use of endosseous one-piece yttrium-stabilized zirconia dental implants in premolar region: a two-year clinical preliminary report	Data available only from 6 months
Borgonovo et al. [45]	Edentulous jaws rehabilitation with yttrium-stabilized zirconium dioxide implants: two years follow-up experience	Follow up experience
Borgonovo et al. [46]	Evaluation of the success criteria for zirconia dental implants: a four-year clinical and radiological study	Reports about the prosthetic outcome and not about implants
Borgonovo et al. [47]	Clinical evaluation of zirconium dental implants placed in esthetic areas: a case series study	Less than 12 subjects
Borgonovo et al. [48]	Multiple teeth replacement with endosseous one-piece yttrium-stabilized zirconia dental implants	Less than 12 subjects
Gahlert et al. [49]	Failure analysis of fractured dental zirconia implants	Only reports failures same study as Gahlert 2013.
Gahlert et al. [50]	Dental zirconia implants up to three years in function: a retrospective clinical study and evaluation of prosthetic restorations and failures	Same cohort patients as Roehling et al.
Jank et al. [51]	Success Rate of Two-Piece Zirconia Implants: A Retrospective Statistical Analysis	Reports about failed implants. Not in-vivo
Kohal et al. [52]	Zirconia-implant-supported all-ceramic crowns withstand long-term load: a pilot investigation	Pilot Study
Kohal et al. [53]	Peri-implant bone response to retrieved human zirconia oral implants after a 4-year loading period: A histologic and histomorphometric evaluation of 22 cases	Reports about failed implants. Not in-vivo
Oliva et al. [54]	One-year follow-up of first consecutive 100 zirconia dental implants in humans: a comparison of 2 different rough surfaces	Same study as the reported after 5 years
Osman et al. [55]	Prosthodontic maintenance of overdentures on zirconia implants: 1-year results of a randomized controlled trial	Reports about the prosthetic outcome and not about implants.
Pirker et al. [56]	Root analog zirconia implants: true anatomical design for molar replacement – a case report	Less than 12 subjects
Schwarz et al. [57]	Non-surgical treatment of peri-implant mucositis and peri-implantitis at zirconia implants: a prospective case series	Does not report about survival rates
Siddiqi et al. [58]	Soft and Hard Tissue Response to Zirconia versus Titanium One-Piece Implants Placed in Alveolar and Palatal Sites: A Randomized Control Trial	Less than 12 subjects
Spies et al. [21]	Alumina reinforced zirconia implants: 1-year results from a prospective cohort investigation	Same study as the reported after 5 years
Spies et al. [59]	Evaluation of Zirconia-Based All-Ceramic Single Crowns and Fixed Dental Prosthesis on Zirconia Implants: 5-Year Results of a Prospective Cohort Study	Reports about the prosthetic outcome and not about implants.
Spies et al. [60]	Bi-layered zirconia/fluor-apatite bridges supported by ceramic dental implants: a prospective case series after thirty months of observation	Reports about the prosthetic outcome and not about implants.

and 36 were selected for full-text screening. Of those, 19 articles were excluded based on the exclusion criteria listed in Table 2. A total of 17 studies met the inclusion criteria and were included in the meta-analysis. All studies were published between 2006 and January 2017.

The included studies were classified according to the following: study type, implant type, mean implant length and diameter, patient count (subdivided by gender and mean age), survival rate, success rate, failure rate, follow-up time, number of implants lost, diameter of lost implants, loading protocol, restoration type (single crowns and fixed dental prosthesis), cement type, restoration material, complications, marginal bone loss (MBL), plaque index (PI), clinical attachment loss (CAL), bleeding on probing (BOP) and bleeding index (mBI), numbers of dropouts and procedure location.

The 17 included studies evaluated a total of 1002 patients with a mean age of 49 (38.5–60) years. This number of clinical studies is low, with a variable follow-up ranging from 1 to 7 years (one-piece: 1–7 years; two-piece: 1–3 years) [39,61]. A total of 1704 implants, including 1521 one-piece implants and 183 two-piece implants, were evaluated in the included studies.

While the studies included in this review investigated the use of one- or two-piece zirconia implants, one study specifically applied one-piece implants with anatomically designed root forms [62].

Noticeably, most of the studies used one-piece zirconia implants [19,21,22,33,35,36,39,40,61]. Thirteen studies included one-piece zirconia implants [16,19,20,22,31,33,34,36,37,39–42,61], 3 studies included two-piece zirconia implants [30,34,38] and 1 retrospective study included both types of implants [32].

Two studies were randomized, controlled clinical trials (RCTs) [33,38] four were retrospective clinical studies [19,31,39,63] and 11 were prospective cohort studies [16,20,30,34–36,38,40,41,61,62].

Five studies were performed in private practices [19,22,32,33,64] while the remainder were performed in academic institutions [16,20,30,31,34–36,38–41]. A combination of both environments was performed in two studies [35,61].

Regarding the implant systems used, most of the studies used the one-piece Z-system [30,33,39,50] and one-piece WhiteSky (Bredent, Senden, Germany) implant systems [31,35,45,46].

3.2. Implant survival

Regarding implant survival, the overall survival rate of the 17 included studies calculated with a random effect model of zirconia implants was 95% (95% CI 91–97%) after observation periods between 1 and 7 years [16,19,21,30,31–36,39,40,61] (Fig. 2). Concerning implant survival considerable heterogeneity was found ($I2 = 79\%$, tau-squared = 0.8219, $p < 0.01$).

Implant survival rates ranged between 76% and 100% after observation periods between 1 and 7 years [31,34].

Due to the lack of sufficient data as well as heterogeneity, a meta-analysis of the success rates could not be performed.

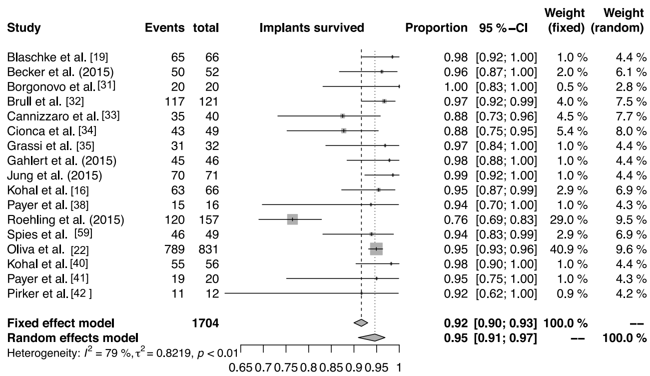

Fig. 2. Forest plot of implant survival.

Meta-analysis was also performed regarding implant design type. Fourteen studies reported one-piece implant survival rates, leading to a survival rate of 95 % (95 % CI 91–97 %) after observation periods between 1 and 7 years. (Fig. 3). Concerning implant survival of one-piece implants, heterogeneity was found (I2 = 82 %, tau-squared = 0.9675, p < 0.01).

The overall survival rate did not vary when excluding the additional 4 studies which included two-piece zirconia implants. Meta-analysis of the two-piece zirconia implant studies was also conducted, having an overall survival rate of 94 % after observation periods between 1 and 3 years (95 % CI 87–97 %) [30,34,38,63] (Fig. 4). Heterogeneity was not statistically significant in the included studies (I2 = 30 %, tau-squared = 0.1978, p = 0.23).

A total of 123 zirconia implants out of 1704 (7.21 %) were lost; of these, 98 were one-piece (6.44 % failure) and 25 were two-piece zirconia implants (13.66 % failure).

Regarding follow up time, the studies included here reported variable follow-up intervals, such as 1 [16,33,34,36,37,40], 1.5 [32], 2 [30,38,41,42], 3 [20], 4 [31], 5 [19,22,35], and 7 years [39].

The study with the longest follow-up (7 years) was a retrospective clinical study evaluating 157 one-piece implants placed in 71 patients [39]. In this study, a total of 36 implants were lost: 14 due to early failure, 4 due to late failure and 18 due to fractures [39]. On the other hand, the shortest follow-up period (12 months) was evaluated in 7 studies [39,61]. Two-piece zirconia implants were followed up during a maximum period of 3 years.

The study with the greatest random weight (9.6 %) showed a survival rate of 95 % after 5 years [22]. 831 one-piece zirconia implants were placed in 378 patients. The study investigated the survival rate of 3 different implant surfaces: uncoated, coated, or acid etched. The survival rates after 5 years ranged between 92.77 %, 93.57 %, and 97.6 %, respectively. Acid-etched implants showed better statistically significant survival rates than the other surface treatments [22].

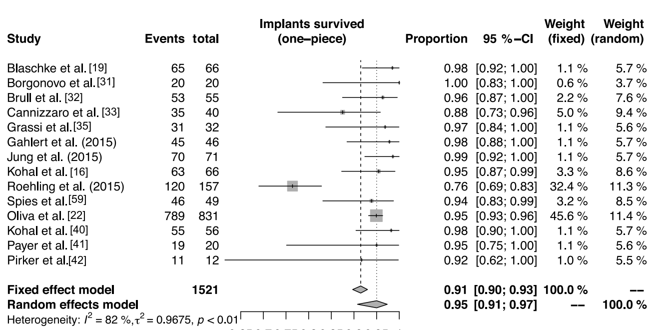

Fig. 3. Forest plot of one-piece implant survival.

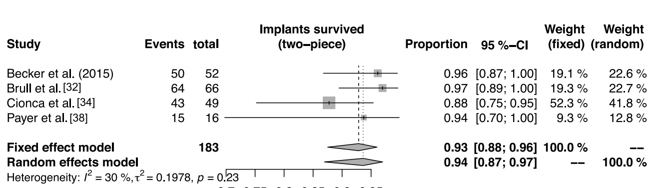

Fig. 4. Forest plot of two-piece implant survival.

3.3. Biological complications

Regarding biological outcomes, a total of 131 biological complications were observed among the studies included in this review. Of those, 18 were periimplantitis [30], 1 hypertrophic tissue [33], 9 a mixture of swelling, infection, and bleeding [61], and 103 cases of non-osseointegration. Only one study reported the frequency of periimplantitis [33]; 18 out of 52 patients (37.5 %) restored with two-piece zirconia implants presented with this biological adverse event. No correlation was found between periimplantitis and any other independent factors investigated [30]. In another study, one case of hypertrophic soft tissue was reported 4 months after loading; to overcome this issue, soft tissues were removed and a new crown was made [33]. Nine biological complications, including, swelling, infection, bleeding and inflammation occurred in one prospective investigation [61]. This represented 18.4 % of the 49 adverse events reported here [61].

As mentioned, 123 implants were lost. The reason for failure in 103 cases was due to a lack and/or loss of osseointegration.

3.3.1. Marginal bone loss

Concerning MBL, 14 studies, with variable follow-ups ranging from 1 to 7 years, evaluated this parameter [16,21,31,33–36,38–41,61,63]. Of these, only 11 were included in the meta-analysis because of standard deviation reporting. These studies reached an overall mean MBL of 0.98 mm (95 % CI 0.79–1.18) after observation periods between 1 and 7 years [16,21,31,33–36,38–41,61,63] (Fig. 5). MBL results ranged between 0.13 mm and 1.95 mm after this period [33,39]. Heterogeneity of the included studies to calculate the MBL was statistically significant (I2 = 96 %, tau-squared = 0.1037, p < 0.01).

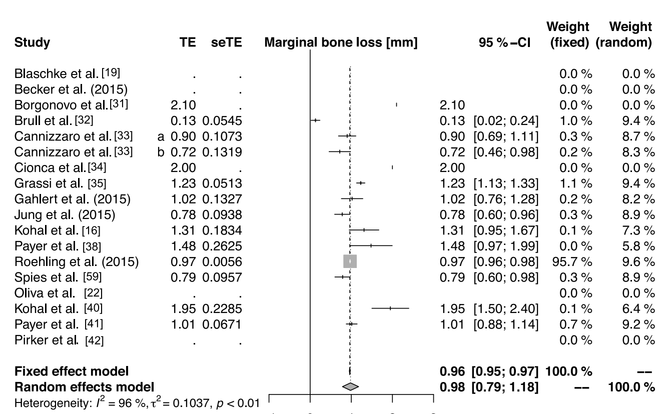

Fig. 5. Forest plot of the overall marginal bone loss.

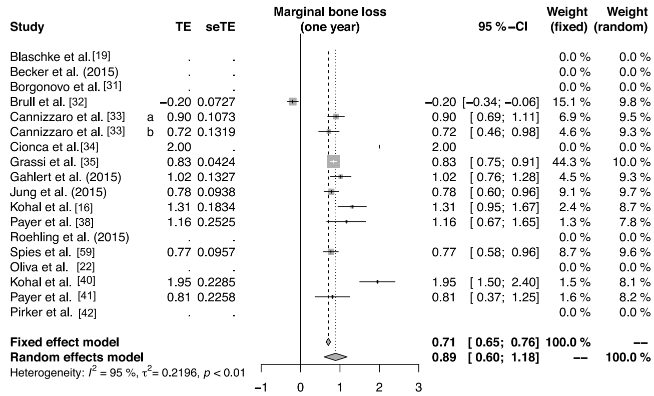

Fig. 6. Forest plot of the marginal bone loss after one year.

The minimum mean MBL was shown in one retrospective study to be 0.13 mm (± 0.6) after an observation period of 3 years, including one and two-piece implants [32]. In contrast, the greatest mean MBL reached was 2.1 mm [31]. Nevertheless, this result could not be included in the meta-analysis due to the absence of standard deviation reporting. Instead, from the studies included in the meta-analysis, the greatest mean MBL reported after 1 year was 1.95 mm (± 1.71) [40]. All one-piece implants in this study supported fixed dental prostheses (FDPs) and were immediately temporized. Forty percent of the MBL was at least 2 mm, 28 % lost more than 3 mm, and 12 % of the patients lost more than 4 mm after one year. The authors concluded that the success rate was significantly lower than the survival rate, due to the high frequency of increased bone loss (≥ 2 mm) [40].

After corresponding with the authors, 10 results of MBL and standard deviation could be analyzed after one year. The mean MBL of zirconia implants calculated in this meta-analysis after 1 year was 0.89 mm (95 % CI 0.60–1.18) (Fig. 6). Heterogeneity of the included studies was statistically significant (I2 = 95 %, tau-squared = 0.2196, $p < 0.01$).

Independent from biological complications, implant-related technical complications were only reported in 3 studies. However, a total of 20 fractures occurred across these 3 included studies [19,63,64]. Eighteen of these fractures occurred in a single retrospective clinical study [39]. Of these 18 fractures, 9 implants fractured in 4 patients diagnosed with bruxism, and 15 had a reduced diameter of 3.25 mm [39]. The remaining 2 fractures occurred in two other studies. One implant fractured due to external trauma and had to be removed; the implant diameter was not specified [19]. For the final fractured implant, neither reason nor diameter were reported [32].

3.4. Prosthetic outcomes

Prosthetic survival and/or success rates were only reported in a few of the clinical studies included in this review. In this systematic review, 588 SCs and 91 FDPs could be evaluated. However, the exact number of restorations could not be obtained due to insufficient data in some studies, which did not report the number of restorations used.

One study included one removable prostheses supported by 4 zirconia implants; we originally decided to include this study due to the high number of included implants. However, these 4 implants were later removed from the analysis after contacting the author [39], since only implants supporting fixed prostheses were included in this study.

Nine studies performed immediate temporization with acrylic restorations; only one study used definitively cemented ceramic crowns. On the other hand, none of the two-piece zirconia implants were immediately temporized [30,38,63,64].

Regarding the selection of restoration material for one- and two-piece zirconia implants, nearly all included studies used all-ceramic restorations, with the exception of one study using composite restorations on one-piece zirconia implants [62]. Ceramics varied from lithium-disilicate (i.e. E.max or Empress II) [22,39,42–45] to zirconia (i.e. Procera) [22,30,34,38,41,63]. The cementation of the restorations was performed either conventionally using glass ionomer cement or adhesive cements such as Panavia F2.0 [19,21,31,32,35,36,40], and Multilink-Automix [16,21,3335,38,40,41,46].

Considering material selection for abutments on two-piece zirconia implants, 2 studies used fiberglass abutments [30,63] while the other 2 studies chose zirconia [34,38]. All two-piece implant abutments were adhesively cemented with Panavia F2.0 [30,63,64] or Multilink-Automix [38]. None of the two-piece zirconia implants presented any screw-retained abutments.

Additionally, no meta-analysis was performed on the prosthetic results with respect to either restoration material or cement type, as the number of restorations as well as restoration survival and success rates were reported by only a few studies.

3.5. Technical complications

A total of 15 technical complications occurred. Of these, 4 were abutment fractures (3 two-piece and 1 one-piece). One fiberglass abutment from a two-piece zirconia implant fractured after 23 months of loading [30], causing the subsequent fracture of the cemented crown. Additionally, the other 2 fractured zirconia abutments of two-piece implants were resolved by cementing new ones [34]. The reason for failure reported by these authors was a communication problem with the laboratory.

Concerning technical complications of one-piece zirconia implants, another abutment fractured due to an unsuccessful removal attempt following failed cementation [36].

Eight prosthetic-related complications occurred in one study (one-piece implants). Most of these events were based on an incorrect calibration of the laboratory scanner, which led to a vertical offset of the final crowns. However, these complications could be resolved by placing new crowns [61]. In one study, 3 crown-related complications occurred [33]. One crown fractured and another crown had to be remade after hypertrophic tissues were removed and the gingiva receded excessively [33]; in this study a crown decementation also occurred.

4. Discussion

This systematic review was designed to evaluate the clinical outcome of zirconia implants in terms of survival rates and mean MBL, as well as prosthetic results of the restorations supported by these implants. To the authors' knowledge, this is the first review that focuses on the implant–restoration complex in addition to the implant outcome. Overall, the results showed comparable outcomes to titanium implants [2]. In this systematic review, focus was given to clinical studies that included at least 10 patients and reported both survival rates and/or MBL and prosthetic restoration results.

The results of this systematic review showed an overall survival rate of 95 % (95 % CI 91–97 %) on zirconia implants after observation periods between 1 and 7 years. In these results, one- and two-piece zirconia implants were included. Segregating the results, one-piece zirconia implants showed a survival rate of 9 5 % (95 % CI 91–97 %), while two-piece zirconia implants showed a survival rate of 94 % (95 % CI 87–97 %).

A greater amount of clinical information is available for one-piece zirconia implants, although the number of randomized prospective trials (2) is still insufficient. The data regarding two-piece zirconia implants is insufficient to conclude a consistent survival rate. Additionally, the observation periods of the studies analyzed here were very heterogeneous ($p < 0.0001$), with the majority reporting only at a 1-year follow-up. No statistically significant difference was found between one- and two-piece implants concerning survival rates ($p = 0.3179$). However, one-piece implants presented a failure of 6.44 %, while two-piece implants showed a greater failure of 13.66 %. All the two-piece implants healed submerged and where lost due to lack of osseointegration just one out of 25 two-piece implants presented a fracture. No study reported about the etiology of the lack of osseointegration. The authors cannot explain any relation to this higher although not statistically significant failure. While these survival rates are considered acceptable, they still do not reach the long-term survival rates of titanium implants.

The greatest individual survival rate included in the meta-analysis was reported in a study with 100 % survival and success rates after a follow-up of 4 years [31]. This prospective study evaluated 14 patients with 20 one-piece zirconia implants, of which 15 were placed in the maxilla and 5 in the mandible. The authors concluded that these exceptional results were due to the high biocompatibility of zirconia surfaces, the low plaque adhesion and the absence of micro-gaps between the implant and the abutment [31].

One difficulty in analyzing multiple studies with respect to clinical success is that the various authors do not all define “success” in a similar manner. Implant success was based only on MBL in 3 studies. Three studies evaluated the success [16,35,40] in grades. These studies classified success grade I as implants with $\leq$ 2 mm of MBL after one year [16,40]. However, success grade II was assumed in two studies as implants with a MBL $\leq$ 3 after 1 year and the other study considered success grade to implants with a MBL > 2 mm after one year [35].

Whenever possible, this analysis quantitated biological complications, which varied from periimplant mucositis, periimplantitis and marginal bone loss to implant loss. Mucositis as such was not reported in all the studies. Unfortunately, not all included studies reported soft tissue parameters. These results could not be statistically analyzed. One study reported soft tissue parameters such as Mombelli’s bleeding index (mBI), probing depth (PD), and clinical attachment level (CAL). This study, the only one reporting on periimplantitis, presented 18 cases [40].

Further regarding soft tissue parameters, in an investigation of two-piece zirconia implants, BOP decreased over 24 months, almost reaching baseline values ($p = 0.124$) [30]. Likewise, a significant reduction in BOP was found in a retrospective study evaluating one- and two-piece zirconia implants after 3 years [32]. In a prospective cohort study of one-piece zirconia implants replacing single teeth, mBI and other soft tissue parameters such as PD, CAL, and mPI decreased significantly [16]. The same group reported these parameters on one-piece zirconia implants restored with 3-unit FDPs. In this study, mBI and PI decreased significantly [40].

Considering MBL as a biological complication, the overall MBL of the included studies in this systematic review was 0.98 mm (95 % CI 0.79–1.18) after observation periods between 1 and 7 years. The mean MBL of zirconia implants was also calculated in this meta-analysis after 1 year; these results (0.89 mm (95 % CI 0.60–1.18)) are comparable to titanium implants. For this calculation, data from one- and two-piece implants were pooled with no distinction on their design. However, longer follow-up studies are needed to confirm their biological performance in terms of MBL and to compare one- and two-piece zirconia implants. Regarding potential causative factors of increased marginal bone loss, it has been suggested that the micro-gap between the implant and abutment could cause micro-movements, and eventually, more severe MBL in cases of two-piece zirconia implants [65].

The next factor contributing to implant success is surface treatment. Implant surfaces can be treated in order to obtain a micro-roughened configuration, thereby increasing the bone-to-implant contact (BIC) and better facilitating the osseointegration process [66]. Two studies included here, investigated the outcomes of different surface treatments [22,62]. One study included 18 patients that were restored with two types of implant surfaces on root-analog, one-piece implants. One type was roughened by sandblasting and the other with additional macro-retentions. None of the implants from the first group survived, while the second group, sandblasted and with macro-retentions, showed a survival rate of 92 %. The conclusion of this study was that macro-retentions seemed to effect improved osseointegration in this immediate root-analogue implant [62]. The other study investigated 3 different surface treatments; coated, uncoated, and acid etched [22]. Survival rates were 92.7 %, 93.57 %, and 97.6 %, respectively. The conclusion of this study was that roughened surfaces might be a viable alternative for zirconia implants [22]. It has previously been documented that rough surfaces on titanium implants show improved osseointegration; this appears to also be the case for zirconia implants.

Beyond biological complications, technical complications were also observed. For example, implant fractures were present in 20 cases. By way of explanation, it is possible that grinding the implant abutment in preparation for subsequent restoration support may induce a crack initiation or propagation along the zirconia implant, which could lead to implant fracture. However, the most frequent complication occurred in a 7-year follow-up, retrospective clinical study [39], in which 18 implants fractured during the loading period. 15 of the fractured implants had a diameter of 3.25 mm, while three implants had a 4 mm diameter. Four patients (accounting for a total of 9 fractured implants) presented with bruxism. The authors suggest that implant fracture could be due to the narrow diameter of the implants and/or bruxism. The final two fractures, occurred in two additional studies [19,32], which did not report the implant diameter, nor did the authors provide any reason for failure. Due to the low number of studies reporting about implant fracture, we recommend implants with standard diameter, but cannot conclude that implant diameter is a causative factor for implant fracture.

Although yittria-stabilised zirconia is the most dominantly used material for the fabrication of zirconia implants, there are other material compositions available. Due to the small number of available studies, proprietary manufacturing processes and different material combination, the current data does not provide evidence to identify which zirconia material would perform best clinically.

Concerning restorations, all the studies analyzed here restored implants with all-ceramic SCs and FDPs [39,50]. However, other restorative options, such as removable prostheses on zirconia implants, have been reported [39]. A 1-year follow up clinical study restored 24 edentulous patients with one-piece zirconia implants [37]. Each patient received 4 implants in the maxilla and 3 implants in the mandible. Implants supporting removable prostheses showed greater bone loss and a higher fracture rate than titanium implants. For this reason, the authors limit their use to patients with titanium allergy. One of the studies included in this review included 4 implants supporting a removable prosthesis on the mandible with a metal bar, which were excluded from the meta-analysis [39]. After contacting the authors for further information, these 4 implants were still in place. However, insufficient data is available to recommend zirconia implants for restoring removable prostheses.

Regarding the choice of restoration material for zirconia implants, all studies used zirconia or lithium-disilicate [21,63,34,61–62], except for one study which used composite restorations [62]. Although there is no information regarding their long-term performance, monolithic restorations seem to present a better option than veneered superstructures. Noticeably, advances in CAD/CAM technologies, along with material improvements, have contributed significantly to the progressive use of such restorations. As no veneering layer is present in monolithic restorations, the inherent problem with chipping or fracture of the veneering ceramic is eliminated. Furthermore, the space typically needed for the veneering layer becomes available for more monolithic material, of particular importance when the distance to the antagonizing dentition/restorations is limited. The selection of the restoration material seems to be based on clinicians' preferences and no recommendation can be provided.

As it has been described in the literature, excess cement can lead to biological complications, e.g. increased MBL and periimplantitis [67]. However, all restorations included in these studies were cemented. The occurrence frequency of periimplantitis was reported in only one study [30], in which 52 two-piece zirconia implants restored with fiberglass abutments and cemented lithium disilicate restorations were evaluated. The crown margins were equigingival so that the remnants of the cement could be easily removed. For this reason, we can conclude that in this review, the observed periimplantitis could not be explained by the presence of excess cement. Furthermore, no correlation could be found with any other influencing factor.

In addition to the restoration material, the outcome of various abutment materials on two-piece zirconia implants should also be evaluated. The material selected for the two-piece implant abutments was either fiberglass [30,63] or zirconia [34,38]. However, no abutment material showed improved outcomes relative to the others. Regarding complications of the abutments, a total of 4 abutments fractured: three were two-piece zirconia implants (1 fiberglass abutment and 2 zirconia abutments) and the fourth a one-piece implant. According to the study authors, the fracture on the 2 zirconia abutments on two-piece implants was due to a communication problem between the clinician and the laboratory [34]. The abutment of the one-piece implant fractured due to a cementation problem. The reason for fracture of the fiberglass abutment of the two-piece implant was not explained in the study but led unfortunately to the subsequent fracture of the crown [30]. It is suggested that this type of implant design is more prone to technical complications than one-piece zirconia implants [23]. 183 two-piece zirconia implants were used with their respective cemented abutment. Based on our review, we cannot conclude that mechanical complications are more frequent in two-piece implants than in one-piece implants. When two-piece zirconia implant abutments fractured, abutments were removed and new ones were cemented onto the intact implants. This reported complication does not have any influence on the implant outcome, and represents a potential advantage of two-piece zirconia implants; in case abutments must be removed for any reason such as abutment fracture, a new one can be cemented in place.

Concerning the cement used for abutment cementation, all restorations included in this review were cemented with Panavia F2.0 [30,63,64] or Multilink-Automix [38]. Alternative retention strategies, such as screw-retained abutments have been discussed as feasible for two-piece zirconia implants. Conversely, none of the studies included in this review used screw-retained abutments. For that reason, no recommendation can be given in terms of screw material and/or restoration protocols. In the reviewed work, no reasons were given by the authors [30,34,38,63] for choosing either fiberglass or zirconia implants or for a particular cement selection. It appears that these choices are more strongly associated with each clinician's comfort and skills rather than with evidence-based indications.

Two-piece zirconia implants usually heal while submerged and in a second step implants are loaded with cemented abutments. In comparison, one-piece zirconia implants are loaded immediately upon placement by various sources of forces such as pressure from the tongue and cheek as well as masticatory forces. For this reason, a thermoplastic splint is used by some clinicians to protect the one-piece zirconia implant abutments from these external forces, which could jeopardize the process of osseointegration [61]. On the other hand, some authors chose immediate temporization of the implants as reported in 9 of the studies included in this review. Each of these used acrylic crowns to provisionally restore the implants, except one using ceramic. However, it is important to note that in cases of one-piece implants, the restoration position is restricted based on bone availability. Due to the lack of angled zirconia implant abutments, a reduced prosthetic versatility is associated with single-piece implants, especially in the aesthetic zone [38]. In some cases, bone augmentation or two-piece implants are required. Currently, only very few clinical studies report on the use of zirconia implants with angled zirconia abutments. This knowledge gap should be considered for future investigations.

5. Conclusion

Although the current evidence shows that one-piece zirconia implants have a very good clinical outcome, long-term clinical studies are still needed to support their clinical use.

Compared to the one-piece design, clinical evidence regarding two-piece zirconia implants remains insufficient to justify their clinical use. Further questions regarding the selection of the abutment material, screw type and retaining method remain unanswered.

As no long-term evidence was identified to support the use of a specific restoration material (lithium disilicate or zirconia), the current use of such materials seems to be based on clinicians' preferences.

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