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Review article

# Zirconia dental implants; the relationship between design and clinical outcome: A systematic review

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ABSTRACT

*Objective:* To evaluate the clinical outcome of different designs of zirconia dental implants.
*Data:* This systematic review adhered to the PRISMA checklist and followed the PICO framework. The protocol is registered in PROSPERO (CRD42022337228).
*Sources:* The search was conducted in March 2023 through four databases (PubMed, Web of Science, Cochrane Library, and Google Scholar) along with a search of references in the related reviews. Three authors reviewed on title, and abstract level and analysed the risk of bias, and all authors reviewed on a full-text level.
*Study selection:* Clinical studies excluding case reports for patients treated with different designs of zirconia dental implants were included. From a total of 2728 titles, 71 full-text studies were screened, and 27 studies were included to assess the risk of bias (ROBINS-I tool) and data extraction. After quality assessment, four studies were included, and the remaining 23 excluded studies were narratively described.
*Result:* The included prospective studies with moderate risk of bias reported success and survival rates of one-piece implants that ranged between 95 and 98.4 % with no difference between different lengths and diameters. The acid-etched roughened surface showed higher clinical outcomes compared to other surface roughness designs.
*Conclusion:* Promising 5-year clinical outcomes were found for one-piece zirconia implants with no difference between different diameters and lengths. Concerning surface roughness, better outcomes were found when using the acid-etched implant surface. However, due to the limited available studies, further high-quality clinical studies comparing zirconia one-piece and two-piece implants with different diameters, lengths, and surface roughness are needed.
*Clinical Significance:* Based on this systematic review, under suitable clinical situations, the one-piece zirconia implants with diameters of 4.0 mm, 4.5 mm, or 5.5 mm and lengths of 8 mm, 10 mm, 12 mm, or 14 mm have similar promising clinical outcomes. Additionally, the acid-etched roughened implant surface may be preferable.

## 1. Introduction

Ceramic dental implants were introduced and used clinically in 1968 by Dr. Sandhaus as a crystallized bone screw [1]. In the seventies and eighties, several implant systems, including the Pfeilstift implant, Cerasand ceramic implant, Bionit implant, Ceramic anchor implant, and Tubingen implant, were introduced. These implants were made from polycrystalline aluminum oxide ($Al_2O_3$) [2]. The monocrystal alumina, which offered a better esthetic appearance compared to the polycrystalline type of alumina, was also used in the same period. Gradually, these types of implants vanished due to the high susceptibility of alumina to fracture under unfavorable stresses [2].

Since the early nineties, zirconium dioxide ($ZrO_2$, zirconia) has been used in different fields of dentistry, especially for dental reconstructions and orthodontic brackets. In medicine, it was initially used for orthopedic implant components such as hip-joint prostheses [3,4]. Currently,

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**Table 1**
PICO items based on the research question.

| | |
|---|---|
| P | **Population:** patient with zirconia dental implant |
| I | **Intervention:** design, e.g., OPI and TPI with different types of surface roughness, diameters, or lengths |
| C | **Comparison:** comparison between different designs of zirconia dental implants (e.g., OPI and TPI) or between types of surface roughness, diameters, or lengths in the same design |
| O | **Outcome:** clinical outcome, i.e., survival rate and success rate, including technical and biological complications |

zirconia is also used as a dental implant material and is mainly produced from yttria-stabilized zirconia (YSZ). The yttria ($Y_2O_4$) doping of zirconia (typically 3 mol%) stabilizes the tetragonal crystal structure. This tetragonal (t) phase is associated with the martensitic toughening mechanism (t – m), which offers improved fracture toughness and flexural strength [3–5]. Moreover, YSZ has osseointegration and soft tissue response properties comparable to titanium (Ti), which is considered the state-of-the-art material for dental implants [6–9]. Furthermore, implants made from zirconia have shown lower cytotoxicity by releasing 50 % fewer particles to the surrounding tissues and offering less bacterial adhesion compared to Ti implants [10,11].

Concerning zirconia dental implants' clinical performance, acceptable and comparable survival and success rates have been reported in comparison to Ti implants. In systematic reviews, the survival rates for zirconia dental implants were reported at 95 % after the first year, decreasing by 0.05 % annually over the following 5 years [6,12,13]. The corresponding figure for the success rates was 91 % [13,14].

Different design alternatives of zirconia implants are currently available. These designs include one-piece implants (OPI) and two-piece implants (TPI) with varying diameters, lengths, and surface roughness. In general, the OPI design consist of fixture and abutment, forming one piece, while the TPI design has the abutment separated from the implant fixture. TPIs have different implant-abutment connections that can be cemented, screwed, or both in combination. These connections can experience marginal leakage, plaque accumulation, and mechanical complications in the joint interface, which can be avoided by using OPIs. The OPI design reduces the risk of complications associated with the contact area within the interface between the implant fixture and the abutment [8,15-17].

Thus, zirconia OPIs are currently more commonly used and recommended due to their promising results, whereas recommendations and clinical evidence on the effectiveness of the zirconia TPI design are limited [8]. However, a retrospective clinical study that compared zirconia OPI and TPI designs reported no difference in survival rates and marginal bone loss [18].

Although the zirconia OPI design shows promising clinical results, it has some limitations. For example, it is less flexible regarding the prosthetic connection, more sensitive to placement (position and angulation), and cannot be used in cases that require two stages or delayed placement. Therefore, there is still a need for a zirconia TPI design that offers flexibility and additional treatment options [8,19,20].

Zirconia implants are available in different diameters, lengths, and surface roughness. Different diameters of zirconia implants have shown dissimilar survival rates, and implants with diameters smaller than 3.5 mm have shown significantly lower survival rates than those with a diameter of 4.0 mm or more [21]. On the other hand, clinical studies comparing different zirconia implant lengths are scarce. Regarding surface roughness, the surface of zirconia implants can be laser-treated, sandblasted, coated with bioactive ceramic compounds, or acid-etched to increase the surface area for the osseointegration [22,23].

Conflicting results have been reported on the osseointegration of zirconia implants regarding bone-to-implant contact area (BIC). Some studies showed no significant difference compared to Ti implants [6,9,24], while in contrast, a study that evaluated tissue response to zirconia dental implants reported a higher rate of osseointegration failure

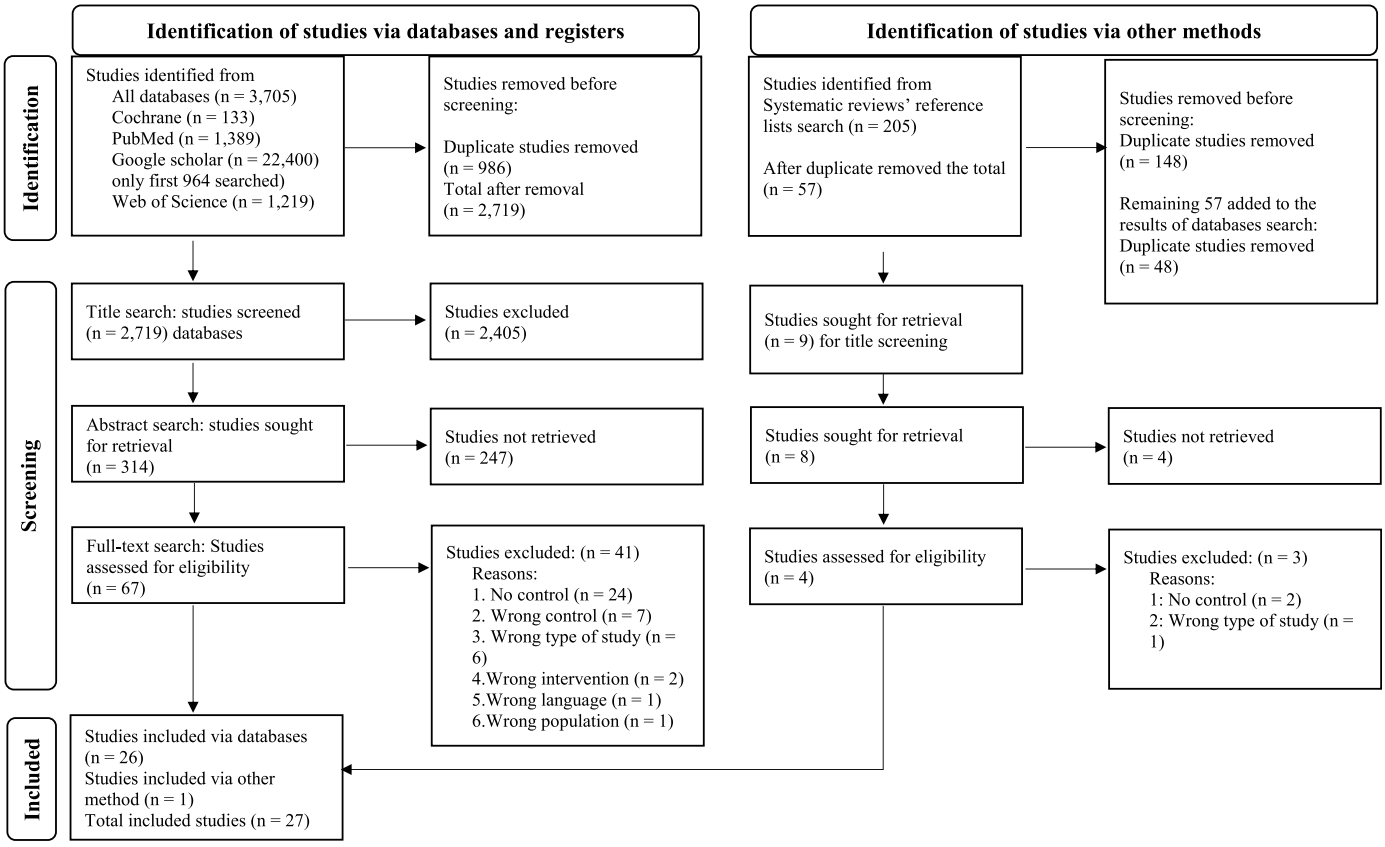


**Fig. 1.** PRISMA flow diagram for new systematic reviews which includes searches of databases and other sources.

**Table 2**
Results of the initial databases search.

| Databases | Search terms | Total identified studies and search date |
|---|---|---|
| PubMed | (Dental implant OR zirconia dental implant OR ceramic implant) AND (zirconia OR zirconium dioxide OR Y-TZP OR 3Y-TZP OR Y-PSZ OR YSZ OR ZrO2) AND (design OR One-piece OR two-piece OR monotype OR 1-piece OR 2-piece) | 1389<br>22.3.2023 |
| Cochrane Library | Dental implant OR zirconia dental implant OR ceramic implant):ti,ab,kw AND (zirconia OR zirconium dioxide OR Y-TZP OR 3Y-TZP OR Y-PSZ OR YSZ OR ZrO2):ti,ab,kw AND (design OR One-piece OR two-piece OR monotype):ti,ab,kw | 133<br>22.3.2023 |
| Google Scholar | (Dental implant OR zirconia dental implant OR ceramic implant) AND (zirconia OR zirconium dioxide OR Y-TZP OR 3Y-TZP OR Y-PSZ OR YSZ OR ZrO2) AND (design OR One-piece OR two-piece OR monotype OR 1-piece OR 2-piece) | The first 964 titles of 22,400<br>22.3.2023 |
| Web of Science | ALL=((Dental implant OR zirconia dental implant OR ceramic implant) AND (zirconia OR zirconium dioxide OR Y-TZP OR 3Y-TZP OR Y-PSZ OR YSZ OR ZrO2) AND (design OR One-piece OR two-piece OR monotype OR 1-piece OR 2-piece) (All Fields) | 1219<br>22.3.2023 |
| Total | | 3705<br>(with only 964 from Google Scholar) |

compared to Ti implants [25]. This failure could be related to the surface of the zirconia implant and the need for modification to enhance the ability to osseointegrate. However, modifying the zirconia surface could be detrimental to its mechanical characteristics and accordingly, its clinical survival [25–27].

Complications associated with zirconia dental implants are divided into two categories: biological (related to the human body) and technical (related to material and design). The incidences of biological complications are 4–8 %, and the most frequently reported complication is loss of osseointegration followed by periimplantitis and other soft tissue complications (e.g., hypertrophic gingiva and gingival recession). Concerning the technical complications, the incidence percentage is 1–2 %, where implant fracture is the most frequent failure occurring during the first seven years in service. Narrow implants in particular showed this type of complication [8,12].

Since zirconia dental implants are a relatively new treatment alternative compared to Ti equivalents, there is not enough evidence on which design of zirconia dental implant has the best clinical outcome. This lack of evidence makes it difficult to determine which design gives the best treatment. Therefore, it is essential to evaluate the clinical outcomes of each design of zirconia dental implant to determine which design provides the best predictable treatment. Thus, this systematic review aims to evaluate the clinical outcome of different designs of zirconia dental implants.

**Table 3a**
Results of ROBINS-I.

| Study | Bias due to confounding | Overall Bias |
|---|---|---|
| 1. Alkhouri (2023) [41] | Critical | Critical |
| 2. Balmer (2018) [42] | Moderate | Moderate |
| 3. Balmer (2020) [43] | Moderate | Moderate |
| 4. Becker (2017) [44] | Critical | Critical |
| 5. Brull (2014) [18] | Critical | Critical |
| 6. Brunello (2022) [45] | Critical | Critical |
| 7. Cannizzaro (2010) [46] | Critical | Critical |
| 8. Cionica (2015) [47] | Critical | Critical |
| 9. Cionca (2021) [48] | Critical | Critical |
| 10. Gahlert (2013) [21] | Critical | Critical |
| 11. Grassi (2015) [49] | Critical | Critical |
| 12. Jung (2016) [50] | Moderate | Moderate |
| 13. Kohal (2012) [51] | Critical | Critical |
| 14. Kohal (2013) [52] | Critical | Critical |
| 15. Kohal (2018) [53] | Critical | Critical |
| 16. Kohal (2020) [54] | Critical | Critical |
| 17. Kohal (2023) [55] | Critical | Critical |
| 18. Kohal (2023) [56] | Critical | Critical |
| 19. Oliva (2007) [57] | Critical | Critical |
| 20. Oliva (2010) [22] | Moderate | Moderate |
| 21. Payer (2013) [58] | Critical | Critical |
| 22. Pirker and Kocher (2009) [59] | Critical | Critical |
| 23. Rodriguez (2018) [60] | Critical | Critical |
| 24. Roehling (2016) [61] | Critical | Critical |
| 25. Rutkowski (2022) [62] | Critical | Critical |
| 26. Sala (2023) [63] | Critical | Critical |
| 27. Steyer (2021) [64] | Critical | Critical |

## 2. Material and methods

This systematic review protocol is registered in PROSPERO under the number CRD42022337228 and follows the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) reporting checklist [28]. Following Schardt et al. [29], we utilized the Population, Intervention, Comparison, and Outcome (PICO) framework to structure the following research question: "What is the clinical outcome of zirconia dental implants with different designs?" The PICO components of this systematic review are presented in Table 1.

### 2.1. Inclusion and exclusion criteria

This review included clinical studies that compared different designs of zirconia dental implants in the same study. Thus, the designs had to be clearly identified in the studies. The inclusion criteria were randomized clinical trials and prospective and retrospective clinical studies.

The review excluded case reports and in vitro studies. In addition, the exclusion criteria were clinical studies with less than 10 patients or less than 10 zirconia dental implants, studies with a dropout rate of patients higher than 20 %, studies with an observation time of fewer than six months, and studies published in a language other than English. Moreover, any implant material other than zirconia was excluded.

### 2.2. Search strategy

A thorough search was done in the following four electronic databases: MEDLINE via PubMed, Web of Science, Cochrane Central Register of Controlled Trials (CONTROL) via Cochrane Library, and Google Scholar. In addition, a manual search was performed on the references of related reviews.

The search of studies published until March 2023 was carried out using the following relevant terms: (Dental implant OR zirconia dental implant OR ceramic implant) AND (zirconia OR zirconium dioxide OR Y-TZP OR 3Y-TZP OR Y-PSZ OR YSZ OR ZrO2) AND (design OR One-piece OR two-piece OR monotype OR 1-piece OR 2-piece).

### 2.3. Study selection

The initial study selection was conducted by three authors (AG, AN-A, and EP) individually by screening the titles and abstracts. Further, a manual search was carried out on the reference lists of related reviews. The identified studies were added to the reference managing tool EndNote 20 [30], where the duplicates were removed using Bramer et al.'s recommendations [31]. Thereafter, the full texts of the selected studies were evaluated by all five authors (AG, AN-A, EP, AR, and PV), who individually reviewed each paper, and studies that fulfilled the inclusion criteria were included. The exclusion and inclusion of the studies by the reviewing authors were done using Rayyan, a web tool for

**Table 3b**
Results of ROBINS-I for the included moderate-risk studies.

| Study | Bias due to confounding | Bias in selection of participants in the study | Bias in classification of interventions | Bias due to deviations from intended interventions | Bias due to missing data | Bias in measurement of outcomes | Bias in selection of the reported result | Overall Bias |
|---|---|---|---|---|---|---|---|---|
| Balmer (2018) [42] | Moderate | Low | Low | Low | Low | Low | Low | Moderate |
| Balmer (2020) [43] | Moderate | Low | Low | Low | Low | Low | Low | Moderate |
| Jung (2016) [50] | Moderate | Low | Low | Low | Low | Low | Low | Moderate |
| Oliva (2010) [22] | Moderate | Low | Low | Low | Low | Moderate | Low | Moderate |

**Table 4**
The final studies included after the risk of bias assessment.

| Study | Type of study | Patient/ Implant | Implant System | Implant material | Implant length /Diameter | Follow-up | Success rate (%) | Survival rate (%) | Early failure (implant) | Late failure (implant) | Implant complications |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Oliva (2010) [22] | Prospective cohort study | 378/ 831 | Specific for study CareRoot SL (Spain) | TZ-3YSB-E, Tosoh. | Customized/ 3 surfaces: 1. UC 2. C 3. ICE | 5 years | Overall:95 UC:92.7 C: 93.5 ICE:97.6 | Overall:95 UC:92.7 C:93.5 ICE:97.6 | 2 | 40 | ——— |
| Jung (2016)[†1] [50] | | 60/71 | Ceramic. implant, vitaclinical, VITA Zahnfabrik, (Germany) | 93 % ZrO2, 5 % $Y_2O_3$, 1.9 % $HfO_2$, and 0.1 % $Al_2O_3$ by weight | 8, 10, 12 and 14 mm /4.0, 4.5 and 5.5 mm | 1 year | 98 4.0mm:100 4.5mm:96.9 | 98.4 4.0mm:96.2 4.5mm:100 | 1 | —— | Biological: 1 periimplantitis |
| Balmer (2018)[†1] [42] | | 54/65 | | | | 3 years | 5.5mm:100 8mm:100 10mm:100 | 5.5mm:100 8mm:100 10mm:97.4 | | | |
| Balmer (2020)[†1] [43] | | 54/64 | | | | 5 years | 12mm:94.8 14 mm:100 | 12mm:100 14 mm:100 | | | |

Abbreviations: UC: uncoated surface. C: coated with a bioactive ceramic coating. ICE: acid-etched surface.
[†] Same studies with different follow-up periods.

systematic reviews [32]. Any disagreements were resolved by consensus via discussions within the research group.

### 2.4. Risk of bias (quality) assessment

Three authors (AG, AN-A, and EP) evaluated the bias and quality of the selected clinical studies using the Cochrane Collaboration's tools for assessing the risk of bias: RoB 2 for randomized trials and ROBINS-I for non-randomized trials [33,34]. Disagreements and doubts were settled through discussion within the research group. Since the first bias domain in the ROBINS-I tool concerns confounding factors, the research group chose the following six confounding factors: general health, oral health, age, smoking, surgical prerequisites, and implant position. Studies with serious or critical risk of bias were excluded.

### 2.5. Data extraction

The extracted data involved the following study characteristics: author and year of study, study design, number of patients, baseline characteristics, number of implants, mean age, implant system, implant material, and implant design. The outcome of different designs and the overall clinical outcomes – namely, the number and type of complications and the success and survival rates of implants – were also extracted from each study. The data were extracted and checked by three authors (AG, AN-A, and EP) individually, disagreements and doubts were settled by discussion within the research group. In the case of data availability, the outcomes of different designs (i.e., the survival and success rates) were interpreted by the data extractor. In the case of missing data, before study exclusion, the corresponding author of the related study was contacted by email to provide the data (with a one-month response time).

### 2.6. Definitions

The success rate is defined as the percentage of implants that remained functional and satisfied the success criteria set in each study. For instance, some studies set a marginal bone loss of $\leq$ 2 mm as a measure of implant success [35,36].

The survival rate is defined as the rate of implants that remained in place and continued to function, whether they were free of complications or have been exposed to some complications that were treated without losing the implant [35,37].

Early implant failure refers to the failure of an implant that occurs within the healing period after implant placement or before prosthetic loading [8,38,39].

Late implant failure is the failure of an implant after six months of placement [38,39].

A technical complication in implants is a complication that occurs within the implant-abutment complex because of the material or implant-related causes, such as implant fracture or abutment fracture [8].

A biological complication is an implant complication that occurs as a reaction from the host body, such as mucositis or periimplantitis [8].

**Table 5a**
Descriptive data for studies that used or compared one-piece implant (OPI) and two-piece implant (TPI) and that were excluded from the systematic review after the risk of bias assessment.

| Study | Type of study | Patient/ Implant | Implant System | Implant material | Implant length /Diameter | Follow-up | Success rate (%) | Survival rate (%) | Early failure (implant) | Late failure (implant) | Implant complications |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Brull (2014) [18] | Retrospective clinical study | 74/121<br>55 OPI<br>66 TPI | Customised | Yttria-stabilized and cerium co-stabilized zirconia blanks (MKMEngineering) | Customized | 3 years | —— | 96.5<br>OPI: 98<br>TPI: 96.8 | 2 | 1 | Technical:<br>1 Implant fracture |
| Rodriguez (2018) [60] | | 12/24<br>10 OPI 14 TPI | Zirkolith, SLM Surface, Z systems (Switzerland) | TZP | 10–13 mm/ 3.25,4.5mm | 5 years | 92 | 92<br>OPI: 90<br>TPI: 92.8 | 1 | 1 | —— |
| Rutkowski (2022) [62] | | 51/150<br>129 OPI 21 TPI | SDS implants, Swiss Dental Solutions AG (Switzerland) | ATZ/TZP (TZP-A) | —— | 1 year | 88 | 92<br>OPI: 92.3<br>TPI: 90.5 | Type of failure not reported<br>12 implants failed | | |
| Sala (2022) [63] | | 18/29<br>18 OPI<br>11 TPI | The Ceralog, Camlog Biotechnologies (Switzerland) | Y-TZP | 8,10,12 mm /4.0mm | 5 years | 91 | 86<br>OPI: 88.8<br>TPI: 81.8 | 4 | —— | Biological:<br>11mucositis |

Abbreviations: TZP, Tetragonal zirconia polycrystal; Y-TZP, Yttria stabilized tetragonal zirconia polycrystal.

### 2.7. Data synthesis

The characteristics and extracted data of the included studies were qualitatively described in tables. A meta-analysis could not be performed on the data of the studies included in this systematic review.

### 2.8. GRADE

A Grading of Recommendations Assessment, Development, and Evaluation (GRADE) was used to evaluate the certainty of the evidence in each outcome in this systematic review. The evaluation involved assessing five domains: risk of bias, indirectness, inconsistency, imprecision, and publication bias. The certainty of the evidence assessment has four overall grades for each outcome that is very high, high, low, and very low. Since no randomized clinical trials were included, the possible gradings started at low quality [40].

## 3. Results

The total number of identified studies from searching the databases and hand-searching the reference lists of related reviews was 3910 studies. The search results, that is, the number of studies (n) identified and included or excluded from the title, abstract, and full-text screening were presented in a PRISMA flow diagram for systematic reviews (PRISMA 2020) that includes the searches of databases and other sources; see the flow chart diagram in Fig. 1. The details of the database search are presented in Table 2.

On a full-text level, a total of 71 studies (67 from the databases and 4 from the manual search) were screened, and 27 studies (26 from the databases and 1 from the manual search) were finally included for risk of bias assessment and data extraction [18,21,22,41-64]. The excluded studies and the reason for exclusion at the full-text level are presented in Appendix Table S1.

The results from the risk of bias assessment are presented in Tables 3a and 3b. Only four studies showed an overall moderate risk of bias and were included in the systematic review (see Table 4) [22,42,43,50]. The remaining 23 studies, which showed a critical risk of bias, were excluded from further analysis and presented descriptively according to the design used in Tables 5a, 5b, 5c, and 5d. All the studies were evaluated as non-randomized clinical studies using the ROBINS-I tool. Most of the studies were deemed critical based on the first domain in ROBINS-I, which is bias due to confounding.

The data from the four included studies, which were prospective cohort studies, are presented in Table 4. However, the data were not enough to perform further statistical analysis. Three of the four studies [42,43,50] investigated the same population with three different follow-up periods: one, three, and five years. Those three studies evaluated 71 OPIs with different lengths (8 mm, 12 implants; 10 mm, 39 implants; 12 mm, 19 implants; and 14 mm, 1 implant) and diameters (4.0 mm, 26 implants; 4.5 mm, 32 implants; and 5.5 mm, 13 implants). They showed a constant overall survival (98.4 %) throughout all three follow-up periods and only one implant failure (4.0 mm diameter, 10 mm length). The success rate was 98 % for the surviving implants, with one implant (4.5 mm diameter, 12 mm length) showing marginal bone loss of more than 2 mm and there is no significant difference between different implant diameters and lengths. The investigated implants were sandblasted and acid-etched and had an average surface roughness (Ra) of 1.2 μm [42,43,50].

The fourth included study had 831 OPIs and compared three different surface roughness designs. All the surfaces were mechanically roughened; thereafter, one group was acid etched (ICE), the second group was coated with a bioactive ceramic coating (C), and the third group was left with an uncoated surface (UC). The ICE, C, and UC groups had a Ra of 1.16 μm, 0.9 μm, and 0.6 μm, respectively [22]. The five years follow-up resulted in 42 failed implants with an overall survival and success rate of 95 % (ICU: 97.6 %, C: 93.5 %, UC: 92.7 %), with the

**Table 5b**
Descriptive data for studies that used or compared one-piece implants (OPI) with different diameters and lengths that were excluded from the systematic review after the risk of bias assessment.

| Study | Type of study | Patient/ Implant | Implant System | Implant material | Implant length /Diameter | Follow-up | Success rate (%) | Survival rate (%) | Early failure (implant) | Late failure (implant) | Implant complications |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alkhouri (2023) [41] | Retrospective clinical study | 51/212 | SDS, Swiss Dental Solutions, (Switzerland) | TZP | 8, 11, 14 mm /3.2, 3.8, 4.3, 4.6, 5.0, 5.6mm | 1 year | 93 | 100 | ——— | ——— | ——— |
| Cannizzaro (2010) [46] | Randomised clinical trial | 40/40 | Z-lock3, Z system, (Switzerland) | ——— | 10,11.5,14 mm/ 3.25,4,5mm | 1 year | ——— | 87.5 | 5 | ——— | Biological: 1 periimplantitis |
| Gahlert (2013) [21] | Retrospective clinical study | 79/170 | Z-lock3, Z system, (Switzerland) | ——— | 10–13 mm/ 3.25,4,5mm | 3 years | ——— | 82.4<br>3.25m:59.5<br>4mm:90.6<br>5mm:73.9 | 14 | 3 | Technical: 13 Implant fracture |
| Grassi (2015) [49] | Prospective cohort study | 17/32 | WhiteSKY, Bredent Medical (Germany) | Y-TZP | 8, 10, 12,14 mm/3.5, 4, 4.5mm | 5 years | 93.75 | 96.8<br>#3.5mm:95<br>4.0mm:100<br>4.5mm:100 | 1 | ——— | ——— |
| Kohal (2012)[†2] [51] | Prospective cohort study | 65/66 | ZiUnite, Nobel Biocare (Sweden) | 3Y-TZP | 10, 13, 16 mm/ 4.3(RP), 5 (WP)mm | 1 years | 66 grade I<br>86 grade II | 95.4 | 3 | ——— | Biological: 5 Pus<br>1 Swelling |
| Kohal (2018)[†2] [53] | | 56/56 | | | | 3 years | 66 grade I<br>79 grade II | 90.8 | ——— | 3 | Biological: 3 periimplantitis<br>12 Pus |
| Kohal (2023)[†2] [55] | | 48/48 | | | | 5 years | 73 grade I<br>88 grade II | 78.2<br>RP:80.6<br>WP:76.6 | ——— | 8 | Biological: 11 periimplantitis<br>23 Pus<br>Technical: 1 Implant fracture |
| Kohal (2013)[†3] [52] | Prospective clinical study | 27/54 | ZiUnite, Nobel Biocare (Sweden) | 3Y-TZP | 10, 13, 16 mm/ 4.3(RP), 5 (WP)mm | 1 years | 60 grade I<br>72 grade II | 98.2 | 1 | ——— | ——— |
| Kohal (2023)[†3] [56] | Prospective cohort study | 24/44 | | | | 3 years | 53 grade I<br>63 grade II | 98.1 | ——— | ——— | Biological: 10 periimplantitis |
| Kohal (2020) [54] | Prospective cohort study | 40/53 | ATZ implant, Metoxit AG (Switzerland) | Alumina-toughened zirconia (ATZ) | 9,12,14 mm/3, 4, 5mm | 5 years | 91.7 grade I<br>100 grade II | 94.3<br>#3.0mm:89<br>4.0mm:100<br>5mm86 | 3 | ——— | ——— |
| Payer (2013)[†4] [58] | Prospective clinical study | 20/20 | WhiteSKY, Bredent Medical (Germany) | Y-TZP | 10, 12, 14 mm/ 3.5, 4 and 4.5mm | 2 years | 95 | 95<br>#3.5mm:87.5<br>4mm:100<br>5mm:100 | 1 | ——— | ——— |
| Steyer (2021)[†4] [64] | | | | | | 11 years | ——— | 80<br>#3.5mm:50<br>4mm:100<br>5mm:100 | 1 | 3 | Biological: 3 periimplantitis |
| Roehling (2016) [61] | Retrospective clinical study | 71/161 | Z-lock3, Z system (Switzerland) | ———- | ———-/ 3.25,4,5mm | 7 years | 77.6<br>3.25m: 58.8<br>4mm: 89<br>5mm: 78.6 | 77.3<br>#3.25mm:58.5<br>4mm:88.9<br>5mm:78.6 | 14 | 22 | Technical: 18 Implant fracture |

Abbreviations: TZP, Tetragonal zirconia polycrystal; Y-TZP, Yttria stabilized tetragonal zirconia polycrystal; RP, regular platform; WP, wide platform.
[†]Same studies with different follow-up periods.

ICE surface design showing statistically significant higher rates than the C and UC surfaces [22].

Overall, all the included studies used a zirconia OPI design, and the success and survival rates for the included OPIs ranged from 95 % to 98.4 % after five years of follow-up [22,42,43,50]. Regarding the technical and biological complications, the former was not reported, and there was only one case of biological implant complication: peri-implantitis [43]. The study by Jung et al. reported one case of early implant failure (due to loss of osseointegration) [50]. While Oliva et al. found that most of the failures were within the first year (90 %), and the rest (10 %) occurred between the first and second year; further, they specified only two cases of early implant failures due to loss of osseointegration, whereas the type of failure in the other cases was not specified [22].

The results of the certainty of evidence evaluation are shown in the GRADE evidence profile (Table 6).

**Table 5c**
Descriptive data for studies that used or compared two-piece implants (TPI) with different diameters and lengths that were excluded from systematic review after the risk of bias assessment.

| Study | Type of study | Patient/ Implant | Implant System | Implant material | Implant length /Diameter | Follow-up | Success rate (%) | Survival rate (%) | Early failure (implant) | Late failure (implant) | Implant complications |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Becker (2017)[†5] [44] | Prospective cohort study | 48/48 | ZV3, Zircon Vision GmbH (Germany) | TZP | 9, 11 or 13 mm/4.5 or 5.0 mm | 2 years | —— | 95.8<br>#4.5mm:100<br>5.0mm:94 | 8 (not counted in the 48 survival) | 2 | Biological: 18 periimplantitis<br>Technical:<br>1 abutment fracture |
| Brunello (2022)[†5] [45] | Retrospective clinical study | 30/30 | | | | 9 years | —— | 94<br>#4.5mm:100<br>5.0mm:90 | | 1 | Technical:<br>6 abutment fracture |
| Cionca (2015)[†6] [47] | Prospective clinical study | 32/49 | ZERAMEX T, Dentalpoint AG (Switzerland) | $ZrO_2$-ATZ-Bio-HIP, (Metoxit AG, Switzerland) | 8, 10, 12 mm/ 3.5, 4.2, 5.5 mm | 1 years | —— | 87.3<br>#3.5mm:100<br>4.2mm:89<br>5.5mm:85 | 1 | 5 | Biological: 3 periimplantitis<br>Technical:<br>1 Implant fracture<br>8 Abutments fractured |
| Cionca (2021)[†6] [48] | Prospective cohort study | 24/39 | | | | 6 years | 63 | 83<br>#3.5mm:100<br>4.2mm:83<br>5.5 mm 85 | —— | 2 | Biological: 18 periimplantitis<br>Technical:<br>1 abutment fracture |

Abbreviation: TZP, Tetragonal zirconia polycrystal.
[†] Same studies with different follow-up periods.

## 4. Discussion

This systematic review focused on clinical studies that compared or used different designs of zirconia dental implants in their investigation. It aimed to evaluate which design of zirconia dental implants provides the best predictable clinical outcomes. The systematic search yielded 27 studies that fulfilled the inclusion and exclusion criteria. However, a quality assessment of the included studies revealed that only four studies had a moderate risk of bias; the remaining 23 studies showed a critical risk for bias and were therefore excluded from the systematic review. The tool used to assess the quality was ROBINS-I, and the critical judgment came from the first domain, which is bias due to the confounding. In ROBINS-I, if any single domain is judged to be critical, the overall judgment of the study is critical [33]. In fact, some of the critically judged studies might be of good quality according to their research questions and aims; however, data related to the aim and the question of the current systematic review were missing in their studies, in a way that those studies were not aiming to compare different designs (i.e. OPI and TPI, different implant lengths and diameters and surface roughness), therefore, information about control of the confounding factors for each evaluated group were missing or scarce. Hence, the corresponding authors of those studies were contacted by email and asked for additional data that could change our judgment. Although 23 studies with low quality were excluded from the systematic review, those studies were still reviewed descriptively.

Only one randomized clinical trial was included in the risks of bias assessment; however, the randomization was done only on choosing the type of temporary restoration that is not of this systematic review interest, this study was judged as non-randomized and assessed accordingly [46].

In this systematic review, the data of the included studies were not enough to perform a meta-analysis. The four included studies presented data only on OPIs, and they evaluated either different lengths and diameters in the same population [42,43,50] or three different designs of surface roughness [22] with a follow-up period of up to five years [22,42,43,50].

The studies by Jung et al. and Balmer et al. reported an overall 98 % success rate and 98.4 % survival rate with no difference between implant length and diameter for all of the follow-up periods [42,43,50]. This rate is close to the one-year survival rate (98.3 %) reported in a previous systematic review of commercially available zirconia implants, and it is only slightly above the two-year survival rate (97.2 %) reported in that same review [8]. Another systematic review reported a 95 % survival for the follow-up period ranging from one to seven years [12]. In a five-year clinical study, Kohal et al. reported a 94 % survival of Alumina-toughened zirconia (ATZ) implants, which is lower than the rates reported in the three included studies [54]. The slight difference could be related to the implant material difference (i.e., the implants in Kohal et al.'s study contain 20 % more alumina than the YSZ used in the included studies) or the more controlled environment for the group of patients involved in the included studies (i.e., they must have enough bone for 4 mm diameter and 8 mm length implant and systematic healthy, and they cannot have non-controlled diabetes or smoke more than 10 cigarettes/day). Furthermore, the low failure rate in the three included studies could be attributed to the implants mostly having 4.0 mm and 4.5 mm diameter, which has been reported in previous research to have a higher survival rate compared to implants with $\leq$ 3.5 mm diameter [21,61,64]. Smaller diameters generally tend to be more exposed to fatigue fracture [21,65,66]. In contrast, a study on another zirconia implant system (Zi-Unite) reported a 78 % survival rate after five years. The authors relate the cause of the high failure rate to the surface roughness technique used in the implant system, which is not available any longer [55].

Thus, surface roughness techniques or designs are of importance to the implants' clinical outcome. Oliva et al.'s study, which is included in this systematic review, compared OPIs with different surface roughness

**Table 5d**
Descriptive data for studies that compared one-piece implants (OPI) with different designs of surface roughness that were excluded from the systematic review after the risk of bias assessment.

| Study | Type of study | Patient/ Implant | Implant System | Implant material | Implant length /Diameter/ surface | Follow-up | Success rate (%) | Survival rate (%) | Early failure (implant) | Late failure (implant) | Implant complications |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Oliva (2007) [57] | Prospective clinical study | 36/100 | CareRoot SL (Spain) specific for study | TZ- 3YSB-E, Tosoh. | Customized/ 2 surfaces: 1. uncoated (UC) 2. coated (C) | 1 year | 98 | 98 | 2 | —— | —— |
| Pirker and Kocher (2009) [59] | Prospective cohort study | 18/18 | Custom-made, root analogue. | Y-TZP | 8, 10, 12 and 14 mm /4.0, 4.5 and 5.5 mm/ 2 surfaces: 1. sandblasted (SB)only 2. adding macro retentions (SB+MR) | 2 years | —— | All SB failed 92 SB+MR | 6 SB and 1 SB+MR | —— | —— |

Abbreviations: Y-TZP, Yttria stabilized tetragonal zirconia polycrystal.

designs and reported a significant difference in the five-year success and survival rates between the acid-etched implants with an average Ra of 1.16 μm (97.6 %) compared to the coated ones with Ra of 0.9 μm (93.5 %) and the uncoated ones with Ra of 0.6 μm (92.7 %) [22]. Thus, the average surface roughness has a direct influence on the survival rates of zirconia implants, which is in line with later studies that reported improved osseointegration with rough zirconia surfaces [27,67,68]. An overall 95 % rate of success and survival was reported by Oliva et al., as only 42 implants out of 831 OPIs failed. Notably, most of the failures were within the first year [22]. This is in accordance with the five-year survival rate of 94 % that was reported in a meta-analysis of zirconia implants restored with all-ceramic single crowns and fixed prostheses [69].

The studies included in this systematic review reported an overall 95 % to 98.4 % range of success and survival after five years of follow-up. Interestingly, the rates for the acid-etched implant group in Oliva et al.'s study and the groups in Jung et al.'s and Balmer et al.'s studies are very close (97.6 % and 98.4 %, respectively), and both used OPIs with a similar average surface roughness (Ra 1.2 μm) [22,42,43,50]. A meta-analysis of different types of zirconia implant surfaces reported significantly higher osseointegration with the acid-etched surface [70].

The fracture of zirconia implants is of great concern since the previous type of ceramic implants made from aluminium oxide was retracted from the market because of low material properties and susceptibility to fracture [2,7]. However, in the included studies, no cases of technical complication were reported, and only one case of biological complication (periimplantitis) was reported in Balmer et al. [43].In total, three identified cases of early failures were reported by Jung et al. and Oliva et al. [22,50]. However, Oliva et al. only identified two cases as early failures from 38 cases of implant failures within the first year, whereas the type and the cause of the remaining 36 cases were not specified [22]. Moreover, Oliva et al. reported four cases of late failures, while none were reported by Jung et al. and Balmer et al. [22,42,43,50]. Consistent with this result, a systematic review of zirconia implant survival showed that early failures were more prevalent in studies on OPIs [71]. This might be related to the nature of OPIs; after insertion, the implant is usually exposed to forces and movement from the tongue or during mastication, which could affect the implant's stability and osseointegration. Nonetheless, in this systematic review, the range of failure rates after five years was only 1.5 % to 5 % for OPIs.

According to the findings in this systematic review, zirconia OPI design showed promising results, this finding is further supported by the recent statement of the German Society for Implantology (DGI) and the position of the European Association for Osseointegration (EAO), on the other hand, further investigation of zirconia TPI was recommended by DGI and EAO [72,73]. Of the studies that were considered as having a critical risk of bias and thus excluded from this systematic review, four studies investigated both OPIs and TPIs [18,60,62,63]. Two of them concluded that after five years, there were no significant differences in survival between OPIs and TPIs [60,63]. Rodriguez et al. reported slightly higher survival for TPIs, and Sala et al. reported higher OPI survival [60,63]. Similarly, there was no significant difference in the survival of both designs after three years [18]. Rutwoski et al. reported survival rates of 92 % for OPIs and 90 % for TPIs after a one-year follow-up [62]. Nevertheless, all the currently available studies are retrospective and judged with a critical risk of bias, according to the risk of bias assessment in this systematic review, and more high-quality studies comparing both designs are needed to better evaluate which design gives the best outcome.

Of the studies that investigated OPIs with different diameters and lengths, three studies reported lower survival rates with narrow diameters OPI ($\leq$ 3.5 mm) compared to standard 4.0 mm OPIs [21,61,64]. On the other hand, four studies that used OPIs with a wide diameter ($\geq$ 5.0 mm) also showed lower survival when compared to the standard diameter of 4–4.3 mm [21,54,55,61]. A possible explanation could be the following: cases that were selected to receive narrow diameter ($\leq$

**Table 6**
GRADE evidence profile.

| Outcome: Survival rate of one-piece zirconia implant with different diameters. Studies: Jung et al. (2016) Balmer et al. (2018); Balmer et al. (2020) [42, 43, 50] | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quality assessment | | | | | | Summary of findings | | | | | | | |
| | | | | | | Number of implants | | | | Survival rate (%) | | | |
| No of studies (Design) | Risk of bias | Indirectness | Inconsistency | Imprecision | Publication bias | Diameters | | | | Diameters | | | Quality |
| | | | | | | 4.0mm | 4.5mm | 5.0mm | | 4.0mm | 4.5mm | 5.0mm | |
| Three publications of one study (prospective cohort) | Moderate ⊖ | No serious indirectness. Two centers in two countries ⊕ | Three publications on the same study group with different follow-up periods. ⊖⊖ | | Undetected ⊕ | 26 | 32 | 13 | | 96.2 | 100 | 100 | |
| Outcome: Survival rate of one-piece zirconia implant with different lengths. Studies: Jung et al. (2016) Balmer et al. (2018); Balmer et al. (2020) [42, 43, 50] | | | | | | | | | | | | | |
| Quality assessment | | | | | | Summary of findings | | | | | | | ⊕ Very Low |
| | | | | | | Number of implants | | | | Survival rate (%) | | | |
| No of studies (Design) | Risk of bias | Indirectness | Inconsistency | Imprecision | Publication bias | lengths | | | | lengths | | | |
| | | | | | | 8.0mm | 10.0mm | 12.0mm | 14.0mm | 8.0mm | 10.0mm | 12.0mm | 14.0mm |
| Three publications of one study (prospective cohort) | Moderate ⊖ | No serious indirectness. Two centers in two countries ⊕ | Three publications on the same study group with different follow-up periods. ⊖⊖ | | Undetected ⊕ | 12 | 39 | 19 | 1 | 100 | 97.4 | 100 | 100 |
| Outcome: Survival rate of one-piece zirconia implants with different surface roughness designs. Study: Oliva et al. (2010) [22] | | | | | | | | | | | | | |
| Quality assessment | | | | | | Summary of findings | | | | | | | ⊕ Very Low |
| | | | | | | Number of implants | | | | Survival rate (%) | | | |
| No of studies (Design) | Risk of bias | Indirectness | Inconsistency | Imprecision | Publication bias | Different surface roughness designs | | | | Different surface roughness designs | | | |
| | | | | | | Acid-etched (ICE) | Coated surface (CS) | Uncoated surface (UC) | | Acid-etched (ICE) | Coated surface (CS) | Uncoated surface (UC) | |
| 1 (prospective cohort) | Moderate ⊖ | No serious indirectness ⊕ | Only one study⊖ Number of implants ⊕ | | Undetected ⊕ | 333 | 249 | 249 | | 97.6 | 93.5 | 92.7 | |

3.5 mm) implants may have had compromised bone width in the implant site, which may have led to future complications, whereas in cases selected to receive wide diameter (≥ 5.0 mm) implants may have had insufficient remaining bone surrounding the wide-diameter implant, causing more bone resorption [74,75]. Most of the technical complications were identified as implant fractures, and according to studies by Gahlert et al. and Roheling et al., who had each found 13 fractures, all the fractured implants had a diameter of 3.25 mm. However, Roheling et al. reported that the manufacturer has removed the 3.25 mm product from the market and replaced it with a new generation of 3.6 mm diameter implants [21,61]. Similarly, most of the biological complications (periimplantitis and pus) were found in one implant system; however, different diameters were involved, and this implant system is no longer available [55,56].

Studies that examined TPI with different diameters and lengths reported survival rates ranged between 83 and 95.8 % [44,45,47,48]. However, the study reported a 95.8 survival rate had 8 early failures that were not counted in the survival rate, and the diameter and length of the early failed implants were not identified [44]. The common complications reported in TPIs were periimplantitis and abutment fracture [44,45,47,48]. These complications could be attributed to the accumulation of bacteria, the leakage of excess cement and the mechanical challenge in the implant-abutment connection area [17,76,77].

Nevertheless, studies on zirconia TPIs are scarce, and there is a need for more high-quality clinical studies on the effect of specific TPI designs and different diameters and lengths on the clinical outcomes of such implants. Multiple zirconia implant manufacturers have recently started making TPIs along with the previously commonly used OPIs. TPIs have different types of implant-abutment connections, and different screw materials are used with screw-type connections; these aspects require further investigation. Thus, as mentioned, TPIs need to be studied further, especially since there is a need to use such a design to reduce the surgical and prosthetic limitations that come with OPIs.

With regards to studies on zirconia OPIs with different surface roughness designs, two studies were reviewed, a study showed a high failure rate in the implant group with only sandblasted roughened surface, but much improvement was seen when adding macroretention to the interdental space and reducing the implant diameter [59]. The other study showed no difference between ceramic coated and uncoated implants [57].

Due to several limitations, the results of this systematic review should be interpreted carefully. Mainly, the limited number of reviewed studies meant that only two study populations were included. Further, according to the GRADE approach, the level of evidence in the reviewed studies was very low.

## 5. Conclusion

This systematic review has found promising five-year clinical outcomes for one-piece zirconia implants with no difference between different diameters and lengths. Concerning surface roughness, better outcomes have been found when using the acid-etched design. However, further high-quality clinical studies comparing zirconia one-piece and two-piece implants with different diameters, lengths, and surface roughness are needed.

## CRediT authorship contribution statement

**Abdulaziz Gul:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Evaggelia Papia:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Aron Naimi-Akbar:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Amund Ruud:** Writing – review & editing, Investigation, Conceptualization. **Per Vult von Steyern:** Writing – review & editing, Supervision, Investigation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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*Data availability statement*

Data is available from the authors upon request.

## Supplementary materials

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