Survival of zirconia implants: a systematic review and meta-analysis

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Master Thesis (30 hp)
Master Program in Dental Science
March 2023

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1. Abstract

Aim
To assess the clinical outcomes of zirconia implants, namely survival rate and the prevalence of fracture, based on a systematic review of the literature.
Material and method
An electronic search was conducted in three databases (PubMed, Web of Science, Science Direct), last updated in October 2022. Inclusion criteria were clinical human studies providing information on implant failure rates in any group of patients receiving zirconia dental implants. Log-rank test was used to compare the survival distributions of implants between some groups of variables. Interval survival rate (ISR) and cumulative survival rate (CSR) were calculated.
Results
Thirty-seven publications were included in the review, with 2941 zirconia implants in 1766 patients, with a mean follow-up of 36.3 ± 22.7 months. There were 182 implant failures, with the great majority of them occurring within the first year after implant installation. Twenty-four implant fractures were reported, most of them in implants of narrow diameter. There was no statistically significant difference of implant failure between the anterior and posterior regions ($p = 0.798$), nor between maxilla and mandible ($p = 0.341$), nor between one- and two-piece implants ($p = 0.787$). The CSR after 10 years was 88.1 %.
Conclusion
Clinical studies assessing clinical outcomes of zirconia implants in humans have a relatively short mean follow-up time. Zirconia implants present a CSR of 88.1% after 10 years, with most failures happening within the first year after implant installation. Implants of narrow diameter present higher risk of fractures than implants of wider diameter.

Keywords: dental implant, failure, implant, meta-analysis, oral implant, systematic review, zirconia implants.

2. Sammanfattning

Syfte
Att bedöma de kliniska resultaten av zirkonia implantat, överlevnadsgrad och förekomst av frakturer, baserat på en systematisk översikt av litteraturen.
Material och metod
En elektronisk sökning gjordes i tre olika databaser (PubMed, Web of Science, Science Direct), senast uppdaterad i oktober 2022. Inklusions kriterier var kliniska humanstudier som gav information om frekvensen av implantatfel hos vilken grupp patienter som helst som fick zirkonia tandimplantat. Log-rank test användes för att jämföra överlevnadsfördelningen av implantat mellan vissa grupper av variabler. Intervallöverlevnadsfrekvens (ISR) och kumulativ överlevnadsfrekvens (CSR) beräknades.
Resultat
Trettio-sju publikationer inkluderades i granskningen, med 2941 zirkonia implantat hos 1766 patienter, med en genomsnittlig uppföljning på 36,3 ± 22,7 månader. Det förekom 182 implantatfel, varav den stora majoriteten inträffades under det första året efter implantatinstallationen. Tjugo-fyra implantatfrakturer rapporterades, de flesta i implantat med smal diameter. Det fanns ingen statistiskt signifikant skillnad av implantatfel mellan de främre och bakre områdena ($p = 0,798$), inte heller mellan maxilla och underkäken ($p = 0,341$), inte heller mellan implantat i ett och två delar ($p = 0,787$). CSR efter 10 år var 88,1 %.
Slutsats
Kliniska studier som bedömer kliniska resultat av zirkonia implantat hos människor har en relativt kort genomsnittlig uppföljningstid. Zirkonia implantat uppvisar en CSR på 88,1 % efter 10 år, med de flesta fel som inträffar inom det första året efter implantatinstallationen. Implantat med smal diameter ger högre risk för frakturer än implantat med bredare diameter.

3. Introduction

3.1. Dental implants - definition and epidemiology

Teeth are very essential body parts, and they may serve a variety of purposes and have a significant influence on a person's quality of life and daily activities (1). A number of daily functions, including speaking and smiling, appear to be impossible without either natural or prosthetic teeth. The capacity to masticate is the most significant function. As a consequence of the tooth's function in communication, chewing, and esthetics, we may argue that teeth and quality of life are related (2).

Unfortunately, teeth are not indestructible and can be lost for a variety of causes during the course of our lives. Teeth are sensory essential organs that need to be taken care of. Caries, periodontal disease, several dental procedures, and trauma are a few examples of factors that result in tooth loss at various ages (3, 4). In addition, it has been shown that an individual's quality of life is positively correlated with the number of teeth that a person has (5). There are a variety of treatment methods available to treat teeth in order to prevent the loss of teeth or even to replace teeth that have been lost.

We are living the dental implant era, and it is becoming common practice to replace lost teeth with implant-supported restorations, which have been showing high degree of suitable functionality and aesthetics, and long-term predictability (6, 7). The modern dental implants were invented in the 1960’s by Per-Ingvar Brånemark, who later coined the concept of osseointegration (8). Brånemark's finding has had a significant influence on dentistry, and it was estimated that more than 7 million Brånemark System implants were placed by the early 2010’s. Hundreds of other companies now manufacture dental implants (9).

As a result, the usage of dental implants shows that between 100,000 and 300,000 dental implants are inserted annually (10). According to the American Academy of Implant Dentistry, 3 million Americans have dental implants, and 500,000 more would be implanted each year (AAID). Furthermore, according to the Swedish Social Insurance Agency (SSIA, Försäkringskassan) (11) over 30,000 patients received implant procedures in 2016 in Sweden, with over 70,000 implantsplaced. There were only slightly more than 20,000 patients in 2009.

3.2. Definition of zirconia implants

As of today, titanium and titanium alloys are the materials most often utilized in implant manufacture, and they have elevated dental implantology to a new level of excellence for tooth replacement. Because of their great biocompatibility, advantageous mechanical characteristics, and well-established positive outcomes, these materials have achieved wide applicability (12, 13). The major disadvantage of titanium is its dark gray hue, which is frequently visible through the peri-implant mucosa and compromises aesthetic results when a thin mucosal biotype is present. Thus, compromise in esthetics may result from poor soft tissue health or gingival resection. This may become more critical when the maxillary incisors are affected (14). Possible unfavorable responses to the metal titanium are another issue. Numerous investigations came to the conclusion that titanium exposure could cause hypersensitivity despite the lack of conclusive proof (15-18).

These negative aspects have led to the development of innovative materials to manufacture dental materials, such as ceramics (19). Ceramics have steadily gained popularity in the dental sector due to esthetic demands. They are now utilized to manufacture not only dental prostheses, but also dental implants. Currently, the preferred materials for ceramic abutments are yttria-stabilized tetragonal zirconia polycrystal ceramics (Y-TZP) and densely sintered alumina (Al_2O_3) (20). But zirconia has consistently outperformed other ceramics when it comes to oral implants in terms of bending strength and fracture toughness (21).

By 2010 there were 9 zirconia dental implant systems available on the market. The first zirconia dental implant system was the Sigma implant, created in 1987 by Sandhause, Incermed, in Lausanne, Switzerland. CeraRoot (Oral Iceberg, Barcelona, Spain), ReImplant (Hagen, Germany), White Sky (Bredent Medical, Senden, Germany), Goei (Goei Inc, Akitsu-Hiroshima, Japan), Konus (Konus Dental, Bingen, Germany), Z-systems (Z-systems, Konstanz, Germany), and Ziterion are other zirconia implant systems (Ziterion, Uffenheim, Germany) (22).

3.3. Zirconia

Zirconium oxide crystallizes as zirconia, which is a material of interest in dental sciences due to comparable white, opaque color to the teeth. Even early claims of superior biocompatibility and low attraction to bacterial plaque. No proof of mutagenic or carcinogenic effects was shown in in vitro research (23). There are three different ways that zirconia crystals can be arranged: monoclinic (M), cubic (C), and tetragonal (T). ZrO_2 can be combined with other metallic oxides such as MgO, CaO or Y_2O_3 to achieve extremely high molecular stability. The preferred ceramic for dental implants now is tetragonal zirconia polycrystal, particularly zirconia stabilized with 3 mol% yttrium oxide (24). It has better mechanical properties than the other combinations such as aluminum oxide (25).

Zirconia has mechanical and physical characteristics such as high flexural strength (900-1,200 MPa), good fracture resistance, resistance to wear and corrosion and low heat conductivity. Zirconia’s excellent properties are due to a phenomenon known as phase transformation toughening (26).
Every change in crystalline reticulation results from a force acting on the zirconia surface, which changes the 4% volume expansion of the crystal under stress. When a stress is applied to a zirconia surface, cracking energy produces a tetragonal to monoclinic transition. This crystalline modification is followed by a crack-sealing expansion. One of zirconia's disadvantages is its low-temperature degradation or aging (27). The other concern about zirconia implants is fracture strength (28).

3.4. Survival of zirconia implants

Several studies have investigated the survival rates of zirconia implants, either in one or two pieces. Some examples follow. In a study published in 2010, a total of 378 patients, with an average age of 48, received 831 zirconia implants. After five years of follow-up, the overall implant success rate was 95% (29).
Clinical and radiographic measures in a study from 2013 revealed that the survival of zirconia single-piece implants that were immediately loaded was 95% after 24 months of follow-up (30), and there was no significant difference in success rates between the 2-piece zirconia implants and the titanium implants (31). In another

study, 35 one-piece zirconium implants were used. After implant insertion, a clinical-radiographic examination was performed every six months. The marginal bone loss (MBL) measurements were calculated for each radiograph. The mean MBL during the first year of loading did not differ significantly between implants placed in the first molar regions and those placed elsewhere. There were no differences in marginal bone level changes between multiple and single implants. MBL in the maxilla was found to be slightly higher for implant placement than MBL in the mandible (32).

In a study published in 2014, 74 patients with 121 zirconia implants (66 two-piece implants and 55 one-piece implants) were clinically evaluated. After three years, three implants failed and had to be removed, for a cumulative implant survival rate of 96.5%. The 118 implants that survived presented a surrounding healthy mucosa, as well as low mean periodontal probing depth (PPD) and bleed on probing (BOP) score (33). Among the 71 patients who received 161 implants in a study published in 2016, 36 implants (22.4%) were lost due to early and late failures or fractures. After 7 years of loading, all 125 implants that survived were successful (34). The overall survival rate for zirconia one- and two-piece implants after one year of function was estimated to be 92% (95% confidence interval 87-95) in a study from 2016 (35).

3.5. Possible complications with zirconia implants

The aging process, often known as low-temperature degradation, is still regarded as one of zirconia's main shortcomings. It is demonstrated that the stabilizer type and content, residual stress, and grain size are the key variables influencing the aging phenomena (27). Slow transformation of the tetragonal to the monoclinic phase at temperatures above 200 °C in the presence of water or water vapor leads to the material's strength, toughness, hardness, and density being reduced. However, the transformation rate is reduced when the particle size is reduced and/or the concentration of stabilizing oxides is increased. Aging is thus caused by compressive stresses and microcracking, and the degree of aging is determined by the balance of these two factors, it may depend on several production-related factors, including the macroscopic shape and surface properties of an implant, although this is not yet fully understood (36).

An in vitro study examining fracture strength has addressed a further issue with zirconia oral implants. It demonstrated that zirconia implants' fracture strength resistance can be decreased by both pretreatment and cyclic loading. Even implants with low mean fracture strength can withstand long intervals of average occlusal loading (28).

There are some of the major concerns about using zirconia implants. The results of study showed a high failure rate for immediately loaded zirconia implants inserted into post-extractive sites (37). Other studies observed that the frequency of increased radiographic bone loss (>2 mm) after one year was significantly higher when compared to titanium implants (38, 39).
Another study reported that, on an implant level, the cumulative mechanical complication such as failure of an industrial component was 17.5%, the cumulative technical complication rate like fractured implant was 13%, the biological complication rate was 8%. However, after 6-year outcomes of a two-piece zirconia implant system, the major long-term complication in this study was abutment fracture (40). Furthermore, failures occurred because of aseptic loosening (41).

4. Aim

The purpose of the present study was to assess the clinical outcomes of zirconia implants based on a systematic review of the literature. The focused question was elaborated by using the PICO format (participants, interventions, comparisons, outcomes): What is the survival rate and the prevalence of fracture of zirconia implants in patients being rehabilitated with implant-supported prostheses?

5. Materials and methods

This study followed the PRISMA Statement guidelines (42). Registration in PROSPERO was undertaken with the registration number CRD 42022342055.

5.1. Search strategies

An electronic search without time restrictions was undertaken in October 2021, with a complementary updating search in October 2022, in the following databases: PubMed/Medline, Web of Science (in "all databases"), and Science Direct. The following terms were used in the search strategies:

("dental implant" OR "oral implant") AND ("zirconia implant" OR "zirconium implant" OR "ceramic implant" OR "zirconia oral implant" OR "zirconia-based ceramic dental implant")

A manual search of all related prosthodontic, implantology, maxillofacial and specialist dental and oral journals was performed. The reference list of the identified studies and the relevant reviews on the subject were also checked for possible additional studies. Grey literature was not searched.

5.2. Inclusion and Exclusion Criteria

Eligibility criteria included clinical human studies, either randomized or not, providing information on implant failure rates in any group of patients receiving zirconia dental implants. Studies that investigated zirconia implants that were manufactured to copy the root anatomy after laser scanning of the extracted tooth were excluded. Exclusion criteria also technical reports, animal studies, in vitro studies, and reviews papers.

5.3. Study selection

The titles and abstracts of all reports identified through the electronic searches were screened independently by two reviewers (AS, PM). For studies appearing to meet the inclusion criteria, or for which there were insufficient data in the title and abstract to make a clear decision, the full report was obtained. The full text assessment was carried out independently by two reviewers. Any disagreements were solved by discussion and if needed by a third reviewer (BRC).
RefWorks Reference Management Software (Ex Libris, Jerusalem, Israel) was used in order to detect duplicate references in different electronic databases.

5.4. Quality assessment

Quality assessment of the included case report publications was carried out according

to the 13-item CARE guidelines (43) were used for the quality assessment of the case report articles. A score of 1 was given for each item outlined in the CARE guidelines, with a maximum score of 30 for a case report. A score of 30 represents the highest quality, and two-thirds or more of the points are considered high quality.

Quality assessment of the included case series studies was carried out according to the Quality Assessment Tool for Case Series Studies of the National Institutes of Health (44). The NIH quality assessment tool calculates the study quality on the basis of nine criteria. The ratings on the different items were used by the reviewers to assess the risk of bias in the study due to flaws in study design or implementation. The studies were classified as "good," "fair," or "poor" quality. In general terms, a "good" study has the least risk of bias, and results are considered to be valid. A "fair" study is susceptible to some bias deemed not sufficient to invalidate its results. The fair quality category is likely to be broad, so studies with this rating will vary in their strengths and weaknesses. A "poor" rating indicates significant risk of bias. Studies of "good" quality were judged to have at least 7 points.

5.5. Definitions

Zirconia dental implants were defined as those being composed of zirconium dioxide (ZrO_2) (45).
An implant was considered a failure if presenting signs and symptoms that led to implant removal, i.e., a lost implant. Implant failure could be either early (the inadequacy of the host to establish or promote osseointegration in the early stages of healing) or late (the failure of either the established osseointegration or function of dental implants) (46). Fracture of an implant was also considered as a failure (47).

5.6. Data extraction

From the studies included in the final analysis, the following data were extracted (when available): year of publication, study design and setting, number of patients, patients' age, implant healing period, implants used (model and brand), jaws receiving implants (maxilla and/or mandible), jaw region (anterior/posterior), number of failed and placed implants, occurrence of implant fracture, type of prosthetic rehabilitation, and follow-up time. When needed, authors were contacted for additional information when data were missing.

5.7. Analyses

The mean, standard deviation (SD), and percentage were calculated for several variables. The test performed were the following: The log-rank (Mantel-Cox) test was used to compare the survival distributions of implants between some groups of variables. The interval survival rate (ISR) of implants was calculated using the information for the period of failure extracted from the included studies, and the cumulative survival rate (CSR) was calculated over the maximal period of follow-up reported, in a life-table survival analysis. The degree of statistical significance was considered $p < 0.05$. These data were statistically analyzed using the SPSS version 28 software (SPSS Inc., Chicago, IL, USA).

6. Results

6.1. Literature search

The study selection process is summarized in Figure 1. The search strategy resulted in 1199 papers (122 in Pubmed/Medline, 192 in Web of Science, and 885 in Science Direct). A number of 224 articles were cited in more than one research of terms (duplicates). Of the resulted 975 studies, 907 were excluded for not being related to the topic. Hand-searching of selected journals did not yield additional papers. The full-text reports of the remaining 68 articles led to the exclusion of 31 because they did not meet the inclusion criteria. Thus, a total of 37 publications were included in the review (for the list of the included studies, see Supplementary Material).

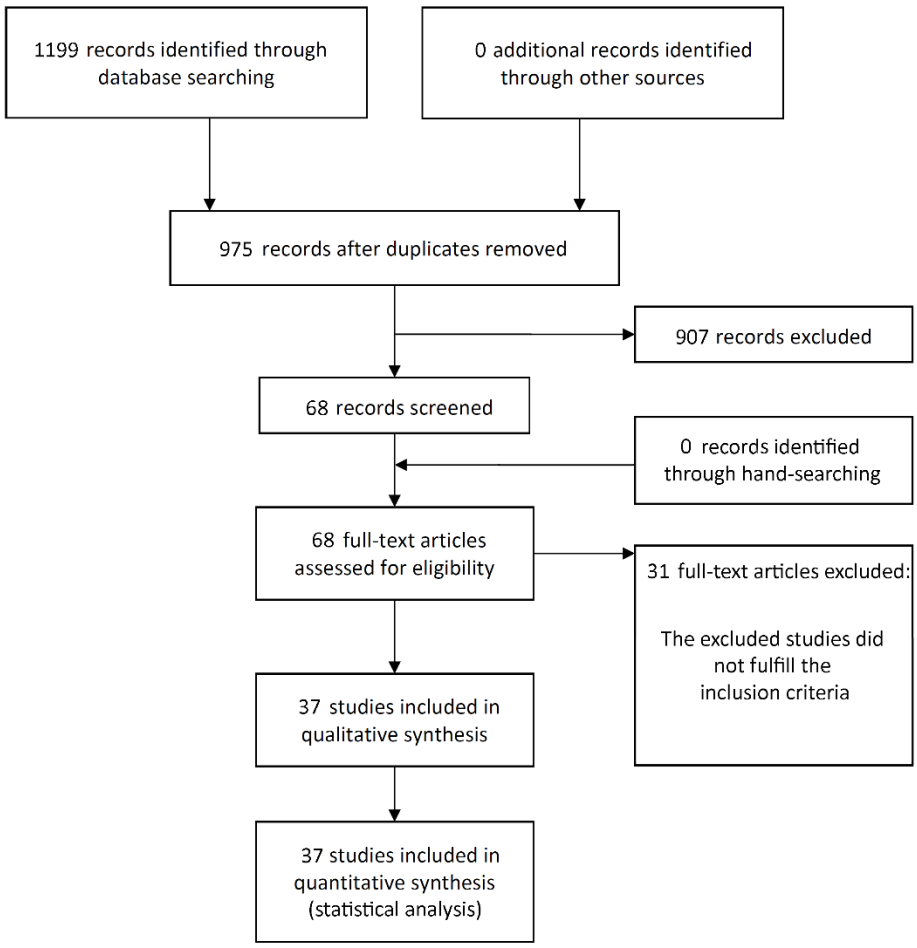

Figure 1. Study screening process.

6.2. Description of the studies

Table 1 presents the summarized data of the included studies. The 37 publications reported 2941 zirconia implants in 1766 patients. The patients consisted of 723 (43.2%) men and 949 (56.8%) women, with no available information on sex for 94 patients. The patients received a mean of 1.49 ± 0.86 (range, 1-7) implants.

There were 182 implant failures, with the great majority of them occurring within the

first year after implant installation (Table 2). Of these 182 failures, 24 were due to implant fracture. Eighteen out of the 24 implant fractures (75.0%) were observed in the study of Roehling et al. (2016)(34). Fifteen out of these 18 fractures in the study of Roehling et al. (2016)(34) occurred with implants of a diameter of 3.25 mm. The location of the failed implants was informed in 79 cases (43.4%) out of the 182 failures, and most of the failures occurred with implants in the posterior region of the jaws. There was no statistically significant difference of implant failure between the anterior and posterior regions ($p = 0.798$; Log-rank test), nor between maxilla and mandible ($p = 0.341$; Log-rank test).

For the great majority of the publications, there was no information if the implant failures occurred in women and/or men. Therefore, an analysis of correlation about failure and sex was not possible. The same was true for patient's age.

Table 1. Summarized data of the included studies – patients rehabilitated with implant-supported prosthesis on zirconia implants (information was not always available for all prostheses for all variables).

Variable	
Patients (n) / Implants (n)	1766 / 2941
Age (years), mean ± SD (min-max)	50.8 **±** 6.4 (18-85)
Sex, n (%)	
Men / Women	723 (43.2) / 949 (56.8)
Not available	94
Implants per patient (n), mean ± SD (min-max)	1.49 ± 0.86 (1-7)
Implant type, n (%)	
One-piece	2742 (93.2)
Two-piece	199 (6.8)
Implant location, n (%)	
Jaw	
Maxilla	1464 (53.5)
Mandible	1274 (46.5)
Not available	203
Region	
Anterior	600 (26.8)
Posterior	1638 (73.2)
Not available	703
Healing time (months), mean ± SD (min-max)	2.55 ± 2.34 (0-11)
Immediate loading, n (%)	1142 (38.8)
0.5-3 months, n (%)	555 (18.9)
4-6 months, n (%)	1197 (40.7)
>6 months, n (%)	47 (1.6)
Prosthesis type, n (%)	
Single crown	925 (86.6)
FDP (2-5 units)	125 (11.7)
Overdenture	18 (1.7)
Not available	698

Follow-up (months), mean ± SD (min-max)	
Implants	36.3 ± 22.7 (0.3-132.0)
Prostheses	32.1 ± 22.4 (1.0-132.0)
Implant failure (n), failure/total (%)	
Implant level	182/2941 (6.2)
Patient level	165/1766 (9.3)
Time of failure (months), mean ± SD (min-max)	14.6 ± 18.1 (0.3-86.0)
Primary failures [a], number/total (%)	39/182 (21.4)
Implant fracture [b], number/total (%)	24 [c]/182 (13.2)
Lost implant replaced by a new one [d], number/total (%)	38/51 (74.5)
Implant location [d], n (%)	
Maxilla anterior	13 (16.5)
Maxilla posterior	27 (34.2)
Mandible anterior	5 (6.3)
Mandible posterior	28 (35.4)
Palate	6 (7.6)
Implant system, n (%)	
ATZ Metoxit	53 (1.8)
ceramic.implant VITA	71 (2.4)
CeraRoot	1117 (38.0)
Nobel Biocare ZiUnite	244 (8.3)
Own manufactured	121 (4.1)
Southern Implants	105 (3.6)
Straumann PURE Ceramic	459 (15.6)
VITA ceramic.implant	46 (1.6)
VOLZIRKON1	22 (0.7)
VOLZIRKON2	22 (0.7)
White-SKY	160 (5.4)
Z-Look3	338 (11.5)
ZERAMAX T	49 (1.7)
Ziraldent FR1	50 (1.7)
Ziterion	16 (0.5)

ZV3	68 (2.3)

FDP – fixed dental prosthesis
[a] Failure up to the abutment connection; 63 out of the 183 failed implants were submitted to the immediate loading protocol
[b] Percentage from the implant cases that failed
[c] Eighteen out of the 24 implant fractures (75.0%) were observed in the study of Roehling et al. (2016)(34)
[d] For the cases with available information

Table 2. Life-table survival analysis showing the cumulative survival rate of zirconia implants

Interval start time (years)	Number entering interval	Number withdrawing during interval	Number exposed to risk	Implant failures	ISR (%)	CSR (%)	SE
0	2941	7	2937.5	115	96.1	96.1	0.36
1	2819	911	2363.5	31	98.7	94.8	0.42
2	1877	195	1779.5	12	99.3	94.2	0.45
3	1670	970	1185.0	6	99.5	93.7	0.49
4	694	88	650.0	7	98.9	92.7	0.62
5	599	437	380.5	9	97.6	90.5	0.94
6	153	14	146.0	0	100.0	90.5	0.94
7	139	125	76.5	2	97.4	88.1	1.89
8	12	1	11.5	0	100.0	88.1	1.89
9	11	0	11.0	0	100.0	88.1	1.89
10	11	0	11.0	0	100.0	88.1	1.89
11	11	11	5.5	0	100.0	88.1	1.89

ISR - interval survival rate (survival rate within each interval)
CSR - cumulative survival rate (cumulative proportion surviving at end of interval)
SE – standard error

6.3. Quality assessment

All included studies were classified as "good" (see Supplementary Material). In most cases the main issue in the publications was related to not well-described statistical methods.

7. Discussion

The present review aimed to evaluate the clinical outcomes of zirconia implants. The implant failure rate was 6.2%. Most of the implants failed within the first years after surgical placement. As there was no detailed information about each and every implant from the included studies, it is hard to make assumptions about which factors in particular could be associated with this result regarding zirconia implants. However, this failure behavior has some resemblance to titanium alloys implants, for which most of the failures are observed in the first years after the implant installation (47, 48).

The site of the failed implants was reported in 79 cases (43.4%) out of 182 failures, and the majority of failures occurred with implants in the posterior portion of the jaws. However, most of the implants were placed in the posterior region of the jaws, and no statistically significant difference in implant failure between the anterior and posterior locations of the jaws or between the maxilla and mandible were observed. Almost half of the early implant failures happened in the posterior maxilla in another study (49). It is not clearly known the reason for that, but implants in posterior locations are usually more susceptible to overloading (50).

A considerable number of failures (13.2%) was due to implant fracture, and 62.5% of the implant fractures occurred in implants of narrow diameter. Implants of narrow diameter are associated with a higher risk of fracture than wider implants (51), particularly when placed posteriorly (52). Scherrer (53) observed that the Z-lock system, which had a 2.7 mm diameter, had a low survival rate of only 59.6%. This did not, however, mean that a larger diameter guarantees better survival, since Roehling (34) observed that an implant body diameter of 5.0 mm had a survival rate of 78.6%, which was lower than implant with a body diameter of 4 mm (88.9%) The diameter-reduced implants with a diameter of less than 3.6 mm were deemed unsuitable for clinical usage by both studies (53). The fracture origins were associated to the sandblasting indentations, it was recognized that the combination of a smaller implant diameter (2.7 mm) and a sandblasted (large grit) surface treatment was detrimental to the implant's ability to survive (53). There is still a significant sensitivity to surface defects associated with zirconia, which is a brittle ceramic material. In order to improve the clinical outcomes of zirconia implants, strict quality control must be implemented during the manufacturing process (54). As the surface integrity of zirconia implants is compromised by surface modifications, early failure is more likely with zirconia implants thanks to its lower shear and tensile strength (21). Zirconia sintered densely is very hard, leading to tool wear or tool failure when milling burs are used. In addition, fine details can be undermilled, and the material will be more susceptible to chipping, chattering, and degradation in terms of mechanical properties (55).

The great majority of the zirconia implants used in the studies were of the type of one-piece implant, which has some advantages. One-piece implants were developed to integrate the transmucosal abutment as an integral element of the implant, providing benefits such as the absence of micro gaps between the implant and abutment, decreased microbial accumulation (56), reduced surgical time, and a simple restorative approach (57). They are intended for immediate use as well as immediate insertion following tooth extraction and can be surgically implanted with or without a flap (57). The immediate-function approach provides advantages over

the late-treatment protocol, such as fewer surgical procedures, shorter treatment duration, and less patient trauma (58, 59).

There is, however, other possible reason for the preference of one-piece implants over the two-piece ones when it comes specifically to implants manufactured of zirconia. It can be hypothesized that the implant manufacture industry was initially skeptical that the thin parts associated with the prosthetic connection of a two-piece implant of zirconia would properly tolerate loads in the same way as the long-tested implants of titanium alloys. Therefore, most (if not all) of the zirconia implants initially available in the market were of the one-piece type. In fact, the first clinical study on zirconia implants was published in 2006, while the first one to include two-piece zirconia implants was published in 2014. Until this date, not so many studies evaluating two-piece zirconia implants have been published. Only 4 out of the 28 studies with available information about this design feature evaluated two-piece zirconia implants. It has been found that fractures most commonly associated with dental implants originate at the abutment neck, the internal connection between the abutment and the implant, and the inner thread of two-piece implants. The fracture origins are associated with damages at the abutment surface of two-piece implants (60). Making the implant in two parts would make the prosthetic connections with very thin structures in some regions, which could make it more susceptible to fractures (51).

One of the advantages of zirconia implants is their natural appearance and feel, which can boost patient self-esteem and quality of life (11, 12). Although we cannot replace titanium implants with zirconia implants, zirconia implants can be a treatment alternative for patients with titanium allergies despite the success rate difference between the two materials (14, 15). However, zirconia implants are often more expensive than other materials, and there is little known about their long-term consequences, including fracture risk. Zirconia implants, on the other hand, have benefits in terms of sustainability due to their stability and capacity to endure severe loads, as well as their recyclability (22)

At the moment, the evidence for a definitive decision is still insufficient, and the field is evolving in a variety of ways. Patients are aware that zirconia implants are available on the market, and we must be prepared to meet their requests.

The study reviewed 37 publications that included 2941 zirconia implants in 1766 patients. The average follow-up period was 36.3 ± 22.7 months, and 182 implant failures were reported, with the majority occurring during the first year after installation. Additionally, 24 implant fractures were reported, mostly in implants with narrow diameters. The study did not find significant differences in implant failure rates based on location or implant type. The study reported a CSR of 88.1% after 10 years. Based on these findings, potential research questions were identified, including investigating the causes of implant failure, the relationship between implant dimensions and fracture risk, and the effect of patient characteristics on implant survival. Further research could help improve our understanding of implant performance and survival rates.

7.1. Methodology

The authors of the present study followed some steps in order to increase the quality

of the review, such as register in PROSPERO, where we get initial feedback of the methodology by some academics.

Moreover, the authors followed the PRISMA guidelines (42), which is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses, that helps to improve clarity and transparency in systematic reviews. The benefits of using PRISMA, includes: (a) it demonstrates the quality of the review, (b) it allows readers to assess strengths and weaknesses, (c) it permits replication of the review methods, and (d) the review is structured and formatted using PRISMA headings. Furthermore, the search was performed in 3 databases and hand (manual) searching was also conducted. Investigators searching for relevant references for a systematic review are generally advised to search multiple databases and to use additional methods in order to maximize the chance to adequately identify all literature related to the topic of interest.

7.2. Limitations of the present study

The results of the present study have to be interpreted with caution because of its limitations. First of all, much of the research in the field is limited by studies with short-term follow-up periods. This might have led to an underestimation of actual failure rates in some studies.

Second, most of the included studies had a retrospective design, and the nature of a retrospective study inherently results in flaws. These problems were manifested by the gaps in information and incomplete records.

Third, there was a wide range of implant systems, one- or two-piece, with different designs, different prosthetic suprastructures, and sometimes implants with different surface modifications.

Fourth, there was a considerable number of confounding factors, and most of the studies, if not all, did not inform how many implants were inserted and survived/lost in several different conditions. It is suggested that factors such as smoking (61), diabetes (62), bruxism (63, 64), insertion of implants in fresh extraction sockets (65), implant length (66), bone quantity and quality of the implant site (67), patient's sex (68), history of periodontitis (69), different surgeons (70), among other factors, may have some impact on the implant survival rate. The impact of these variables on the implant survival rate is difficult to estimate if these factors are not identified separately between the different implant groups in order to perform a meta-regression analysis.

8. Conclusions

Considering the results of the present review, the following can be concluded:

- The mean follow-up of the included studies is short, namely 36 months.
- The cumulative survival rate of zirconia implants is 88.1% after 10 years.
- Most of the failures happen during within first year after implant installation.
- There is no significant difference in failure rate between implants placed in maxilla and mandible, in anterior and posterior regions of the jaw, nor between one- and two-piece implants.

- Most of the implant fractures (62.5%) happen with zirconia implants of narrow diameter.

9. Acknowledgements

We would like to thank the following authors who provided us additional information about their studies (in alphabetical order of the surname): Dan Hagi and Kristian Kniha.

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10.2. Supplementary material – Quality assessment

Study	Year	Was the study question or objective clearly stated?	Was the study population clearly and fully described, including a case definition?	Were the cases consecutive?	Were the subjects comparable?	Was the intervention clearly described?	Were the outcome measures clearly defined, valid, reliable, and implemented consistently across all study participants?	Was the length of follow-up adequate? [a]	Were the statistical methods well-described?	Were the results well-described?	Total (n/9)
Alshali	2021	1	1	0	1	1	1	1	0	1	7/9
Balmer	2020	1	1	0	1	1	1	1	1	1	8/9
Becker	2017	1	1	0	1	1	1	1	1	1	8/9
Blaschke	2006	1	1	1	1	1	1	1	0	0	7/9
Borgonovo	2011	1	1	0	1	1	1	1	0	1	7/9
Borgonovo	2012	1	1	1	1	1	1	1	0	1	8/9
Borgonovo	2013a	1	1	0	1	1	1	1	0	1	7/9
Borgonovo	2013b	1	1	1	1	1	1	1	1	1	9/9
Borgonovo	2015	1	1	1	1	1	1	1	0	1	8/9
Brüll	2014	1	1	1	1	1	1	1	1	1	9/9
Cannizzaro	2010	1	1	1	1	1	1	1	1	1	9/9
Cionca	2021	1	1	1	1	1	1	1	1	1	9/9
Gahlert	2022	1	1	1	1	1	1	1	1	1	9/9
Grassi	2015	1	1	0	1	1	1	1	1	1	8/9

Hagi	2021	1	1	1	1	1	1	1	0	1	8/9
Kniha	2017	1	1	1	1	1	1	1	1	1	9/9
Kniha	2018a	1	1	1	1	1	1	1	0	1	8/9
Kniha	2018b	1	1	1	1	1	1	1	1	1	9/9
Kohal	2013	1	1	1	1	1	1	1	1	1	9/9
Kohal	2018	1	1	1	1	1	1	1	1	1	9/9
Kohal	2020	1	1	1	1	1	1	1	1	1	9/9
Koller	2020	1	1	1	1	1	1	1	1	1	9/9
Kunavisarut	2020	1	1	1	1	1	1	1	1	1	9/9
Lorenz	2019	1	1	0	1	1	1	1	0	1	8/9
Oliva	2010	1	1	1	1	1	1	1	0	1	8/9
Osman	2013	1	1	1	1	1	1	1	0	1	8/9
Osman	2014	1	1	1	1	1	1	1	1	1	9/9
Roehling	2016	1	1	0	1	1	1	1	0	1	7/9
Ruiz Henao	2021	1	1	1	1	1	1	1	1	1	9/9
Scaringi	2021	1	1	0	1	1	1	1	0	1	7/9
Spies	2015	1	1	1	1	1	1	1	1	1	9/9
Spies	2016a	1	1	1	1	1	1	1	1	1	9/9
Spies	2016b	1	1	1	1	1	1	1	1	1	9/9

Spies	2019	1	1	1	1	1	1	1	1	1	9/9
Steyer	2021	1	1	0	1	1	1	1	0	1	7/9
Tawil	2020	1	1	0	1	1	1	1	0	1	7/9
Vilor-Fernández	2021	1	1	0	1	1	1	1	0	1	7/9

[a] 3 months of follow-up was chosen to be of adequate length.