Current Trends of Zirconia in Implant Dentistry: A Narrative Review

Arbaz Sajjad[1*]; Nurul Fathiah Binti Hj Awang Mahli[2]; Jagjit Singh Dhaliwal[3]

[1]Assistant Professor; [2] Undergraduate Student; Senior Lecturer[3]

[1;2]Pengiran Anak Puteri Rashidah Sa'adatul Bolkiah Institute of Health Sciences, Universiti Brunei Darussalam, Jalan Tungku Link, Gadong, BE1410 Brunei

[3]School of Medicine and Dentistry, Griffith University, QLD4222

Corresponding Author: Arbaz Sajjad*

Publication Date: 2026/03/19

Abstract:

- ***Background:***

Dental implants have revolutionized modern dentistry by offering reliable solutions for tooth replacement. Zirconia dental implants have emerged as potential alternatives to titanium, driven by increasing demand for metal-free and aesthetically superior solutions.

- ***Aim:***

This systematic review explores current trends in zirconia as a viable alternative dental implant material by analyzing recent advancements in mechanical properties, osseointegration potential, and clinical performance over the past decade (2015-2025).

- ***Methods:***

A literature search was conducted in PubMed database (2015-2025) to identify systematic reviews, meta-analyses, and structured literature reviews examining mechanical properties, osseointegration, and clinical outcomes of zirconia dental implants. English-language articles with minimum 6-week follow-up periods were included, focusing on comparisons of implant designs and surface modification techniques.

- ***Results:***

Zirconia dental implants demonstrate low fracture rates (0.65%), though performance varies with material composition, implant design, and surface modifications. Alumina-toughened zirconia (ATZ) exhibits superior mechanical stability compared to yttria-stabilized tetragonal zirconia polycrystal (Y-TZP). One-piece implants show greater fracture resistance than two-piece designs. Surface modifications including acid etching and laser treatments enhance bone-to-implant contact, though improper application may compromise mechanical integrity.

- ***Conclusion:***

Despite promising clinical outcomes, optimal surface modification protocols remain controversial. Zirconia implants demonstrate favorable results, particularly one-piece implants with adequate diameter (≥4.0 mm) and optimized surface treatments. Long-term clinical studies are essential to establish standardized protocols and confirm reliability as titanium alternatives.

Keywords: *Zirconia Dental Implants, Mechanical Properties, Osseointegration, Clinical Outcomes, and Surface Modifications*

How to Cite: Arbaz Sajjad; Nurul Fathiah Binti Hj Awang Mahli; Jagjit Singh Dhaliwal (2026) Current Trends of Zirconia in Implant Dentistry: A Narrative Review. *International Journal of Innovative Science and Research Technology*, 11(3), 1470-1477. https://doi.org/10.38124/ijisrt/26mar904

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar904

I. INTRODUCTION

Dental implants have transformed modern dentistry as reliable solutions for replacing missing teeth, restoring oral function and aesthetics in patients with partial or complete edentulism [1]. Patients expect implants to restore their normal appearance and enable confident social interactions [2]. For decades, titanium has been the gold standard material for dental implants, with well-documented biocompatibility, excellent mechanical properties, and high success rates [3]. However, titanium presents several limitations: grey color compromising aesthetics, potential hypersensitivity reactions to metals, and susceptibility to corrosion when exposed to fluoride [4]. These concerns have driven demand for alternative materials, particularly ceramic dental implants offering aesthetic advantages through their tooth-like appearance [4].

The evolution of ceramic dental implants began in 1977 with commercially available mono- or poly-crystalline aluminum oxide (Al_2O_3) implants [5]. These early ceramic implants were subsequently withdrawn from the market due to insufficient mechanical strength and poor clinical outcomes [6]. Contemporary ceramic dental implants are predominantly fabricated from yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), characterized by enhanced fracture toughness from tetragonal crystal structure [7], superior corrosion and wear resistance, and high flexural strength (800-1000 MPa) compared to other dental ceramics [4]. Zirconia (ZrO_2) has found widespread applications in dentistry, including dental restorations, orthodontic brackets, and implants [5].

Research demonstrates that zirconia dental implants exhibit high biocompatibility with favorable soft tissue response [4], releasing approximately half the particulate matter into surrounding tissues compared to titanium and displaying reduced bacterial adhesion [8]. Enhancing structural integrity of zirconia dental implants to achieve optimal mechanical properties represents an active research area, with investigations evaluating clinical outcomes across different implant designs. These designs include one-piece (OPI) versus two-piece (TPI) configurations, which differ in diameter, length, and surface roughness parameters that influence fracture resistance, flexural strength, and fatigue behavior. OPI designs integrate fixture and abutment into a single unit, whereas TPI designs feature separate abutment and implant fixture components.

Despite zirconia's mechanical strength, successful long-term function requires adequate bone integration. Bone formation on implant surfaces is influenced by surface roughness characteristics. Early failure rates of zirconia implants generally exceed those of titanium implants, primarily attributed to insufficient osseointegration—the process by which implants integrate with surrounding bone [9]. Osseointegration can be quantified through bone-implant contact (BIC) percentage and removal torque value (RTV). BIC represents the percentage of implant surface directly contacting surrounding bone tissue, with higher values indicating superior osseointegration. Surface modification techniques including sandblasting, acid etching, and laser treatment have been extensively explored to enhance osseointegration in zirconia implants, with studies suggesting acid-etched zirconia achieves BIC comparable to or exceeding titanium [10]. Research indicates surface-treated zirconia implants achieve higher BIC values than machined surfaces, similar to titanium implants [11]. RTV measures rotational force required to remove a dental implant from surrounding bone following healing, with higher values indicating better osseointegration.

Surface modifications can influence mechanical properties, particularly fracture resistance of zirconia [12], consequently affecting clinical survival. Heat and acid treatments may reduce zirconia's flexural strength through uncontrolled phase transformation and low-temperature degradation [13]. Phase transformation refers to the shift from tetragonal to monoclinic structure in aqueous environments, potentially causing surface cracking and diminished mechanical strength. However, this transformation mechanism underlies transformation toughening, a ceramic strengthening phenomenon that absorbs energy and impedes crack propagation, thereby enhancing zirconia's fracture resistance and toughness. During crack formation, stress at the crack tip induces tetragonal-to-monoclinic transformation, resulting in 3-4% volume expansion. This expansion generates compressive stress that closes the crack and prevents propagation [14].

The effectiveness of this toughening mechanism depends on tetragonal phase stabilization, achieved by adding stabilizers such as yttria (Y_2O_3). Y-TZP maintains the tetragonal phase at room temperature, enabling the material to benefit from transformation toughening without premature phase change. As zirconia continues evolving as a dental implant material, comprehensive evaluation of survival rates and potential failure factors from clinical outcomes becomes essential.

This narrative review aims to analyze current trends in zirconia as a viable alternative dental implant material by examining recent advancements in mechanical properties, osseointegration potential, and clinical performance over the past decade (2015-2025).

II. METHODS

A. Search Strategy

A systematic literature search was conducted from January 2015 to December 2025 in the PubMed database to identify relevant peer-reviewed publications regarding mechanical properties, osseointegration, and clinical outcomes of zirconia dental implants. The 10-year timeframe ensures the review reflects current trends and advancements in the field, providing insights into how different implant designs and surface modifications influence performance and outcomes. The literature search was restricted to English-language articles.

B. Search Terms

The following keyword combinations were employed:

- "Zirconia dental implants AND mechanical properties" (28 results)
- "Zirconia dental implants AND osseointegration" (46 results)

- "Zirconia dental implants AND clinical outcomes" (124 results)

A total of 198 articles were initially identified. Titles and abstracts were screened, followed by full-text evaluations for potentially eligible studies (Figure 1).

C. Inclusion and Exclusion Criteria

The inclusion criteria were restricted to English-language articles published between 2015 and 2025 (Table 1) that focused specifically on zirconia dental implants and reported on implant design or surface modifications, as well as mechanical performance, osseointegration, or clinical outcomes such as bone-to-implant contact, removal torque values, and survival or success rates. Eligible publications were required to be higher-level evidence, including systematic reviews, meta-analyses, or structured literature reviews, and to be based on in vivo, in vitro, or clinical trials with a minimum follow-up duration of six weeks for animal or clinical data. Studies were excluded if they were case reports, individual clinical studies, or expert opinions not embedded in a structured review, if they primarily compared materials other than zirconia (for example, titanium versus zirconia), or if full-text articles were not accessible in PDF format.

D. Study Selection

Of 198 results, 5 papers met inclusion criteria for the zreview. All papers included systematic reviews, meta-analyses, and structured literature reviews with comprehensive assessments of zirconia dental implant performance.

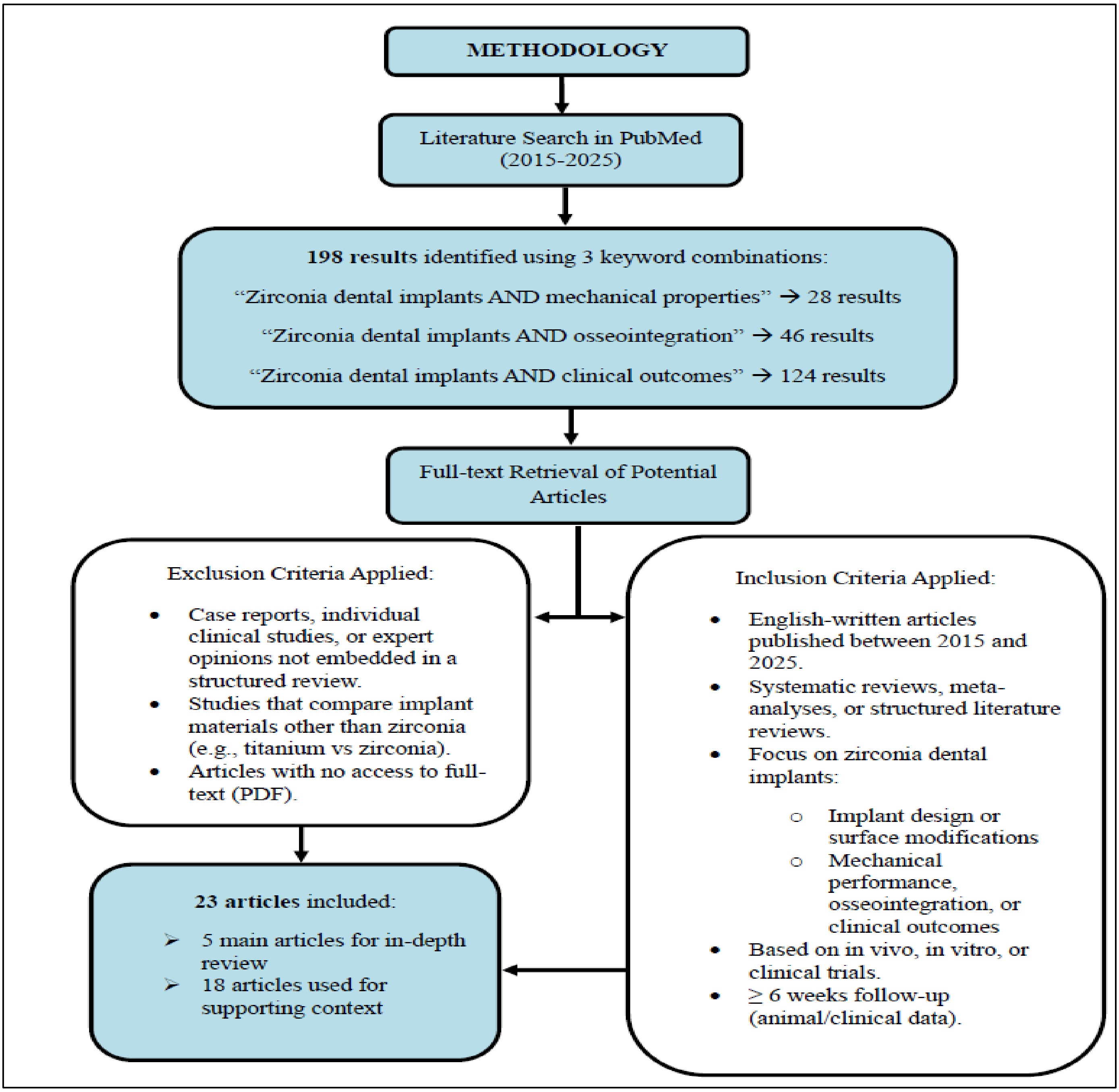

Fig 1: Search Strategy for the Narrative Review

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar904

To ensure reliability and validity of included studies, preference was given to studies with higher-level evidence (systematic reviews and meta-analyses), particularly those reporting robust methodology including risk of bias assessments, sufficient follow-up durations, and well-defined sample populations.

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III. RESULTS

❖ *Mechanical Properties*

A. *Fracture Resistance*

Fracture resistance in zirconia dental implants represents a critical property enabling the material to endure stresses encountered in the oral environment. This ability to withstand stress prevents crack propagation, essential for maintaining implant integrity under functional loading such as masticatory and biting forces. Systematic reviews demonstrate that while zirconia implants can exhibit fractures, overall fracture rates remain relatively low. One review of over 4,000 zirconia dental implants reported 0.65% fracture incidence [15], comparable to fracture rates observed in large cohorts of titanium implants [16].

However, fracture strength of zirconia implants is not fixed and can be negatively influenced by both pretreatment processes and cyclic loading in the oral environment. Despite this susceptibility, mean fracture strength values of zirconia implants tested in studies generally appear capable of withstanding average occlusal forces [15]. Nevertheless, considerable variation in normal chewing forces—ranging from 110-125 N in posterior dentition and 60-75 N in anterior dentition, with potentially higher forces during parafunctional habits such as bruxism [17]- emphasizes the need for robust fracture resistance.

B. *Material Composition: Y-TZP versus ATZ*

The primary zirconia composition used in dental implants is Y-TZP, well-established for its balance of aesthetics and mechanical properties. Stabilizers including yttria are added to zirconia to control phase transformation, balancing toughness and long-term durability. While the five systematic reviews do not extensively compare Y-TZP directly with ATZ regarding fracture resistance, one study suggested toughening zirconia with alumina for increased mechanical stability, as ATZ implants showed significantly higher fracture strengths than Y-TZP implants [18]. Alumina increases hardness while zirconia contributes toughness through transformation toughening, creating a stronger composite than Y-TZP alone. This suggests compositional variations within zirconia-based materials can influence mechanical behavior.

Table 1: Inclusion and Exclusion Criteria for Article Selection

Inclusion Criteria	Exclusion Criteria
English-written articles published 2015-2025	Case reports, individual clinical studies, or expert opinions not embedded in structured review
Systematic reviews, meta-analyses, or structured literature reviews	Studies focusing on comparing implant materials other than zirconia
Studies focusing on zirconia dental implants, especially implant design, surface modifications, mechanical performance, osseointegration, or clinical outcomes	
Studies including in vivo, in vitro, or clinical trials as part of review base	Articles with no access to full-text (PDF)
Follow-up duration ≥6 weeks (for animal or clinical data)	

C. *Material Composition: Y-TZP versus ATZ*

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ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar904

D. Implant Design: One-Piece versus Two-Piece

Implant design significantly affects mechanical performance of zirconia implants. In vitro studies suggest OPIs demonstrate greater fracture resistance than TPIs, with most zirconia implants fabricated as one-piece due to material limitations [15]. This increased resistance in OPIs is attributed to the absence of connection interface, which in TPIs can be a stress concentration point and potential failure site. Prosthetic connections in TPIs involve thinner structures initially viewed skeptically regarding load-bearing capacity compared to titanium alloys. Fractures in TPIs often originate at abutment neck, internal connection, or inner thread, highlighting vulnerability of interface areas [19].
However, OPI presents limited adaptability for prosthetic connections, greater dependence on precise placement regarding position and angulation, and unsuitability for cases requiring two-stage or delayed placement approaches [20].

E. Implant Dimensions

Implant dimensions, particularly diameter, significantly influence mechanical strength. Narrow-diameter implants (≤3.5 mm) exhibit reduced fracture resistance and greater susceptibility to fatigue failure compared to implants with diameters ≥4.0 mm. In vitro studies confirm narrower zirconia implants (3.0-3.3 mm) have lower flexural strength, with 3.0 mm implants failing fatigue tests while wider implants demonstrate better mechanical performance [15,20].

Research directly comparing mechanical properties of zirconia implants of varying lengths remains limited, with few studies investigating their impact on fracture resistance and fatigue behavior.Descriptively, higher educational attainment appeared associated with greater awareness of tooth replacement options, suggesting that education may facilitate exposure to oral health information.

F. Surface Modifications and Mechanical Properties

Surface modifications primarily aim to enhance osseointegration; however, they can inadvertently affect mechanical strength of zirconia implants. While machined zirconia surfaces have shown promising biocompatibility and osseointegration [13], modifications such as sandblasting are employed to increase surface roughness for improved BIC [10]. However, aggressive surface treatments can potentially introduce micro-cracks and defects, compromising zirconia's mechanical properties [15].

Excessive grit blasting could result in surface flaws acting as crack initiation sites [21]. Achieving optimal surface roughness (Sa of 1-1.5 μm) is crucial, as excessive roughness may be detrimental to mechanical stability. Laser surface modification, while achieving high surface roughness and favorable biological responses, has been reported to induce very low amounts of preload microcracks, suggesting potentially advantageous surface treatment balancing biomechanical and osseointegrative properties [22].

Acid etching, often used in conjunction with sandblasting, has generally shown positive effects on osseointegration, but its impact on long-term mechanical strength of zirconia requires further investigation [10]. According to Schünemann et al., grit blasting, acid etching, and heat treatment should not reduce zirconia's flexural strength and fracture toughness [13]. However, degradation rates can increase due to excessive thermal treatment, high concentrations of hydrofluoric acid (HF), and lengthy etching times. For grit blasting, smooth and round particles are advised to reduce micro-cracks. Transformation toughening from tetragonal to monoclinic phase may occur due to stress concentration from grit blasting, creating compressive stress and crack resistance, but uncontrolled transformation due to aging and environmental factors can degrade mechanical stability over time. Zhang et al. found that compressive stress from grit blasting was insufficient to counteract strength loss due to micro-cracks under high static loads and fatigue conditions [23].

❖ *Osseointegration*

A. Bone-to-Implant Contact

Osseointegration represents the process by which dental implants become securely anchored in bone, beginning with blood clot and fibrin matrix formation around the implant, providing a scaffold for cell migration. Over time, woven bone forms at the implant site, followed by distance and contact osteogenesis, where new bone forms at a distance and directly on the implant surface. As healing progresses, woven bone fills the gap around the implant and matures into strong, organized lamellar bone. The osseointegration of zirconia dental implants, characterized by direct BIC and mechanical stability indicated by RTV, represents a critical factor for long-term clinical success [13].

B. Unmodified and Machined Surfaces

One study found unmodified zirconia dental implants had similar BIC percentages to acid-etched and grit-blasted titanium implants [21]. Additionally, unmodified zirconia implants may achieve better BIC than machined and modified surfaces [10]. Machined zirconia implants can be as osseointegrated as machined titanium implants [10]. However, another study reported that selective infiltration-etched zirconia implants showed improved BIC over time, suggesting certain modifications may enhance long-term bone integration [24].

C. Acid Etching

Acid etching has emerged as a particularly promising surface modification for zirconia implants. A systematic review and meta-analysis concluded that acid-etched zirconia implants exhibited significantly better BIC values compared to titanium implants in animal models [10], suggesting acid etching creates surface topography highly conducive to bone cell attachment and growth.

HF etching has been identified as a key surface modification technique promoting bone apposition and improving implant stability, indicated by higher implant removal torque values [25,26]. Studies have shown HF-etched zirconia implants exhibit high BIC values, with one study reporting 81% BIC for commercially available HF-treated zirconia implants [27]. Furthermore, roughness of zirconia

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar904

does not appear significantly influenced by variations in etching time or acid concentration [28].

D. Laser-Treated Surfaces

Laser surface modification represents a more recent technique showing exceptional potential for enhancing osseointegration [14]. Review by Jin et al. identified laser-modified surfaces as having the highest surface roughness and BIC values among techniques in reviewed literature, including sandblasting, acid etching, or combinations thereof [22]. This method allows precise control of surface topography, potentially leading to optimal bone ingrowth. Cell proliferation was highest in laser-treated compared to blasted followed by acid-etched, blasted only, and polished surfaces. Furthermore, laser modification has been reported to induce very low levels of microcracks, potentially beneficial for long-term mechanical stability [22].

E. Removal Torque Values

Bond strength between bone and implant, often measured by RTV, reflects osseointegration effectiveness and has been explored in relation to zirconia surface modifications. According to Hafezeqoran and Koodaryan's review, all five included studies reported significantly higher RTV for untreated zirconia implants compared to machined zirconia implants [10]. However, Gahlert et al.'s study found significantly higher RTV for grit-blasted zirconia compared to machined zirconia [29].

Grit blasting and acid etching have been shown to increase surface roughness, leading to improved removal torque strength and bone stability in animal studies [29]. This aligns with Aboushelib et al.'s study finding zirconia implants with rougher surfaces exhibited higher resistance to removal torque in rabbit models [24]. Further comparisons among different surface treatments revealed that selective infiltration-etched and acid-etched surfaces combined with heat treatment had the highest surface roughness, surpassing blasted and machined surfaces [30]. Additional acid etching not only increased surface roughness but also smoothed sharp edges typically found on blasted surfaces, highlighting complexity of surface modifications and need for careful consideration of specific techniques.

❖ *Clinical Outcomes*

A. Survival Rates

Clinical performance of zirconia dental implants has been increasingly evaluated in recent years, with systematic reviews providing valuable insights into long-term outcomes. Overall, zirconia implants have demonstrated promising survival and success rates, often comparable to titanium implants [15].

B. Material Composition

Material composition may influence clinical performance of zirconia implants. In a five-year clinical study, Kohal et al. reported 94% survival rate for ATZ implants [18], compared to findings of Mohseni et al., where most studies focused on Y-TZP and reported 95.1% 10-year cumulative survival rate (CSR), indicating good long-term outcomes [15]. Higher mechanical stability of ATZ due to added hardness from alumina may contribute to its performance; however, differences in study duration limit validity of direct comparisons between the two materials.

C. Implant Design

Implant design, particularly distinction between OPI and TPI implants, has been examined. Mohseni et al. in their systematic review and meta-analysis reported that two-piece implants presented lower survival rates than one-piece implants [15]. In contrast, Gul et al.'s systematic review noted that studies excluded due to critical risk of bias showed mixed results, with some finding no significant difference in survival between OPIs and TPIs after five years, while others reported slightly higher survival for either design [20].

D. Implant Dimensions

Implant size, especially diameter, appears to be a critical factor for survival. Gul et al. reported that implants with diameters smaller than 3.5 mm have shown significantly lower survival rates compared to those with diameters ≥4.0 mm [20]. This is consistent with Mohseni et al., who found that the majority of implant fractures occurred in narrow-diameter implants [15].

Conversely, clinical studies comparing different zirconia implant lengths are scarce. One systematic review found no significant difference in success and survival rates between different implant lengths and diameters in included studies; however, moderate risk of bias in these studies may have affected result reliability and potentially obscured true differences [20].

E. Surface Modifications

Surface modifications, while primarily studied for their impact on osseointegration, may also indirectly affect long-term clinical outcomes. Gul et al. concluded that better outcomes were found when using acid-etched implant surfaces [20]. Similar high success and survival rates were reported by Oliva et al. for acid-etched OPIs with similar surface roughness [31]. Thoma et al. found that unmodified zirconia implants had higher fracture rate after six months compared to acid-etched and grit-blasted titanium implants [21]. Unmodified zirconia typically has smooth surface, which can hinder optimal osseointegration. In contrast, acid-etched and grit-blasted titanium implants have roughened surfaces promoting better mechanical interlocking with bone, leading to improved primary stability and load distribution.

F. Failure Rates

Complications associated with zirconia implants include both biological and technical issues [20]. Biological complications, with 4-8% incidence, most frequently involve loss of osseointegration and peri-implantitis. Technical complications, occurring at 1-2% rate, are often related to implant fracture, particularly in narrower implants and during the first seven years of service. Mohseni et al. reported that implant fracture accounted for 15.1% of all implant failures in their review [15]. Furthermore, implants with coronal part prepared by drills showed statistically significant lower survival, potentially due to increased fracture risk. Gul et al.

noted that early failures were more prevalent in studies on OPIs, possibly due to immediate exposure to forces [20].

IV. DISCUSSION

With growing demand for metal-free, aesthetic dental solutions, zirconia implants have gained significant clinical interest. However, their long-term success depends on multiple mechanical and biological factors that must be critically assessed. The findings indicate that while fracture rate of zirconia implants is low (0.65%), their mechanical performance is strongly influenced by implant design, material composition, and surface treatments [15].

Material composition affects implant strength, with ATZ possessing superior mechanical behavior compared to Y-TZP [18]. OPIs are shown to be more fracture-resistant compared to TPIs due to absence of connection interface, which is generally an area of stress concentration [15]. Narrow diameter implants, especially 3.0 mm, demonstrate significantly lower survival rates and are not recommended for clinical use [15,20].

Surface modifications represent another critical factor for implant success. While machined zirconia implants have been found to provide adequate osseointegration, surface treatments such as acid etching, grit blasting, and laser modifications have been employed to enhance BIC and RTV [10,13,22]. Acid etching, particularly with HF, has been shown to produce favorable results in surface roughening and osseointegration enhancement [10,25,26]. However, overexposure to acid can compromise mechanical integrity through surface degradation and increased susceptibility to fracture [13]. Similarly, grit blasting has been found to increase surface roughness but may generate micro-cracks as stress concentrators, reducing long-term durability [13,23].

The relevance of this review is that it contributes to comprehensive understanding of the compromise between mechanical strength and osseointegration of zirconia implants. Surface treatments enhance biological integration, yet they need to be carefully optimized to prevent adverse effects on mechanical stability. The transformation toughening mechanism inherent to zirconia provides unique strengthening properties through tetragonal-to-monoclinic phase transformation [14]. However, excessive or uncontrolled transformation induced by inappropriate surface treatments can lead to microcracking and compromised durability.

Overall, zirconia implants show promising clinical outcomes, particularly for one-piece implants with adequate diameter (≥4.0 mm) and optimized surface treatments. The 10-year cumulative survival rate of 95.1% for Y-TZP implants is encouraging [15], though long-term comparative studies with titanium implants remain necessary. The balance between achieving enhanced osseointegration through surface modifications while maintaining mechanical integrity represents a key challenge in zirconia implant development.

V. LIMITATIONS

Although this review prioritized high-quality studies such as systematic reviews and meta-analyses, several limitations should be acknowledged. First, reliability and validity of selected papers, while supported by structured methodologies, are not guaranteed without more in-depth critical appraisal of each individual study. For instance, one of the included reviews is based entirely on animal studies, limiting its applicability to human clinical outcomes. Another is a narrative literature review without formal risk of bias assessment, which may reduce robustness of its conclusions. Some systematic reviews also reported limitations such as low certainty of evidence, limited number of included studies, or lack of control for confounding variables. In addition, variations in study designs, sample sizes, and surface modification techniques across the literature further complicate direct comparison and synthesis.

VI. CONCLUSION

Zirconia dental implants represent a promising alternative to titanium implants, offering superior aesthetics and biocompatibility. Current evidence demonstrates low fracture rates and favorable 10-year survival rates for Y-TZP implants. Material composition, implant design, dimensions, and surface modifications significantly influence mechanical and clinical performance. ATZ exhibits superior mechanical properties compared to Y-TZP, while one-piece implants demonstrate greater fracture resistance than two-piece designs. Surface modifications, particularly acid etching and laser treatment, enhance osseointegration as measured by BIC and RTV. However, optimal surface modification protocols remain controversial, requiring careful balance between enhanced biological integration and maintained mechanical integrity. Despite these advancements, the need for further research to establish standardized protocols is evident.

REFERENCES

[1]. Arefnia B, Fakheran O, Jakse N, Payer M. Patient-reported outcomes of zirconia dental implants: a systematic review and future directions. J Patient Rep Outcomes. 2025;9(1):7.
[2]. Arefnia B, Fakheran O, Jakse N, Payer M. Patient-reported outcomes of zirconia dental implants: a systematic review and future directions. J Patient Rep Outcomes. 2025;9(1):7.
[3]. Sivaraman K, Chopra A, Narayan AI, Balakrishnan D. Is zirconia a viable alternative to titanium for oral implant? A critical review. J Prosthodont Res. 2018;62(2):121-133.
[4]. Apratim A, Eachempati P, Krishnappa Salian K, Singh V, Chhabra S, Shah S. Zirconia in dental implantology: A review. J Int Soc Prev Community Dent. 2015;5(3):147-156.
[5]. Gul A, Papia E, Naimi-Akbar A, Ruud A, Vult von Steyern P. Zirconia dental implants; the relationship between design and clinical outcome: A systematic review. J Dent. 2024;143:104903.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26mar904

[6]. Andreiotelli M, Wenz HJ, Kohal RJ. Are ceramic implants a viable alternative to titanium implants? A systematic literature review. Clin Oral Implants Res. 2009;20(Suppl 4):32-47.
[7]. Pieralli S, Kohal RJ, Lopez Hernandez E, Doerken S, Spies BC. Osseointegration of zirconia dental implants in animal investigations: A systematic review and meta-analysis. Dent Mater. 2018;34(2):171-182.
[8]. He X, Reichl FX, Milz S, Michalke B, Wu X, Sprecher CM, et al. Titanium and zirconium release from titanium- and zirconia implants in mini pig maxillae and their toxicity in vitro. Dent Mater. 2020;36(3):402-412.
[9]. Padhye NM, Calciolari E, Zuercher AN, Tagliaferri S, Donos N. Survival and success of zirconia compared with titanium implants: a systematic review and meta-analysis. Clin Oral Investig. 2023;27(11):6279-6290.
[10]. Hafezeqoran A, Koodaryan R. Effect of Zirconia Dental Implant Surfaces on Bone Integration: A Systematic Review and Meta-Analysis. BioMed Res Int. 2017;2017:9246721.
[11]. Al Qahtani WMS, Schille C, Spintzyk S, Al Qahtani MSA, Engel E, Geis-Gerstorfer J, et al. Effect of surface modification of zirconia on cell adhesion, metabolic activity and proliferation of human osteoblasts. Biomed Tech (Berl). 2017;62(1):75-87.
[12]. Sanon C, Chevalier J, Douillard T, Cattani-Lorente M, Scherrer SS, Gremillard L. A new testing protocol for zirconia dental implants. Dent Mater. 2015;31(1):15-25.
[13]. Schünemann FH, Galárraga-Vinueza ME, Magini R, Fredel M, Silva F, Souza JCM, et al. Zirconia surface modifications for implant dentistry. Mater Sci Eng C Mater Biol Appl. 2019;98:1294-1305.
[14]. Cunha W, Carvalho O, Henriques B, Silva FS, Özcan M, Souza JCM. Surface modification of zirconia dental implants by laser texturing. Lasers Med Sci. 2022;37(1):77-93.
[15]. Mohseni P, Soufi A, Chrcanovic BR. Clinical outcomes of zirconia implants: a systematic review and meta-analysis. Clin Oral Investig. 2024;28(1):5.
[16]. Chrcanovic BR, Kisch J, Albrektsson T, Wennerberg A. Factors influencing the fracture of dental implants. Clin Implant Dent Relat Res. 2018;20(1):58-67.
[17]. Ferrario VF, Sforza C, Zanotti G, Tartaglia GM. Maximal bite forces in healthy young adults as predicted by surface electromyography. J Dent. 2004;32(6):451-457.
[18]. Kohal RJ, Wolkewitz M, Mueller C. Alumina-reinforced zirconia implants: survival rate and fracture strength in a masticatory simulation trial. Clin Oral Implants Res. 2010;21(12):1345-1352.
[19]. Zhang F, Monzavi M, Li M, Čokić S, Manesh A, Nowzari H, et al. Fracture analysis of one/two-piece clinically failed zirconia dental implants. Dent Mater. 2022;38(10):1633-1647.
[20]. Gul A, Papia E, Naimi-Akbar A, Ruud A, Vult von Steyern P. Zirconia dental implants; the relationship between design and clinical outcome: A systematic review. J Dent. 2024;143:104903.
[21]. Thoma DS, Benic GI, Muñoz F, Kohal R, Sanz Martin I, Cantalapiedra AG, et al. Histological analysis of loaded zirconia and titanium dental implants: an experimental study in the dog mandible. J Clin Periodontol. 2015;42(10):967-975.
[22]. Jin HW, Noumbissi S, Wiedemann TG. Comparison of Zirconia Implant Surface Modifications for Optimal Osseointegration. J Funct Biomater. 2024;15(4):91.
[23]. Zhang Y, Lawn BR, Malament KA, Van Thompson P, Rekow ED. Damage accumulation and fatigue life of particle-abraded ceramics. Int J Prosthodont. 2006;19(5):442-448.
[24]. [Aboushelib MN, Salem NA, Taleb ALA, Moniem NMA El. Influence of surface nano-roughness on osseointegration of zirconia implants in rabbit femur heads using selective infiltration etching technique. J Oral Implantol. 2013;39(5):583-590.
[25]. Misch CE, Perel ML, Wang HL, Sammartino G, Galindo-Moreno P, Trisi P, et al. Implant success, survival, and failure: The International Congress of Oral Implantologists (ICOI) pisa consensus conference. Implant Dent. 2008;17(1):5-15.
[26]. Steyer E, Herber V, Koller M, Végh D, Mukaddam K, Jakse N, et al. Immediate Restoration of Single-Piece Zirconia Implants: A Prospective Case Series—Long-Term Results after 11 Years of Clinical Function. Materials (Basel). 2021;14(22):6738.
[27]. Rodriguez AE, Monzavi M, Yokoyama CL, Nowzari H. Zirconia dental implants: A clinical and radiographic evaluation. J Esthet Restor Dent. 2018;30(6):538-544.
[28]. Roehling S, Woelfler H, Hicklin S, Kniha H, Gahlert M. A Retrospective Clinical Study with Regard to Survival and Success Rates of Zirconia Implants up to and after 7 Years of Loading. Clin Implant Dent Relat Res. 2016;18(3):545-558.
[29]. Gahlert M, Roehling S, Sprecher CM, Kniha H, Milz S, Bormann K. In vivo performance of zirconia and titanium implants: a histomorphometric study in mini pig maxillae. Clin Oral Implants Res. 2012;23(3):281-286.
[30]. Bergemann C, Duske K, Nebe JB, Schöne A, Bulnheim U, Seitz H, et al. Microstructured zirconia surfaces modulate osteogenic marker genes in human primary osteoblasts. J Mater Sci Mater Med. 2015;26(1):26.
[31]. Oliva J, CeraRoot Dental Implants. Five-year success rate of 831 consecutively placed zirconia dental implants in humans: A comparison of three different rough surfaces. J Oral Maxillofac Implants. 2010;25(2):336-344.