The Original

CURRENT ADVANCES IN ZIRCONIA IN PROSTHODONTICS: A NARRATIVE REVIEW

Dr. Yashika Bali[1] , Dr. Anshul Trivedi[2] , Dr. Navya Vashisth[3*]

[1]Associate Professor, Department: Prosthodontics and Crown & Bridge, Subharti Dental College and Hospital, Swami Vivekanand Subharti University, Meerut (Uttar Pradesh) Email: yashika1990@yahoo.com ORCID: 0000-0002-5322-7378.
[2]Associate Professor, Department: Prosthodontics and Crown & Bridge, Subharti Dental College and Hospital, Swami Vivekanand Subharti University, Meerut (Uttar Pradesh) Email: dranshulmsaxena@gmail.com ORCID: 0000-0002-9090-6759
[3*]Junior Resident, Department: Prosthodontics and Crown & Bridge, Subharti Dental College and Hospital, Swami Vivekanand Subharti University, Meerut (Uttar Pradesh) Email: vashisthnavya@gmail.com ORCID: 0009-0009-2407-9116

ABSTRACT
Zirconia has emerged as one of the most important metal-free biomaterials in prosthodontics because of its high mechanical strength, favorable fracture resistance, acceptable esthetics, and good biocompatibility. This narrative review aimed to critically evaluate the composition, properties, processing methods, clinical applications, limitations, and recent advances of zirconia used in prosthodontics. A narrative literature search was carried out using electronic databases including PubMed, Scopus, and Google Scholar, along with manual screening of relevant references. Keywords related to zirconia, prosthodontics, Y-TZP, monolithic zirconia, CAD/CAM, implant abutments, and low-temperature degradation were used to identify relevant English-language publications from early landmark reports to recent studies. The selected literature was analyzed through a thematic narrative approach under material science, processing technologies, biological behavior, clinical applications, and current limitations. The reviewed evidence indicates that zirconia possesses excellent strength and fracture toughness, largely due to transformation toughening, while newer generations have shown improved translucency and enhanced esthetic potential. CAD/CAM technology has become the dominant method for zirconia fabrication because of its precision, reproducibility, and wide clinical applicability. However, important limitations remain, including low-temperature degradation, veneer chipping in bilayered restorations, and challenges associated with surface treatment and durable bonding. Within these limitations, zirconia continues to be a key prosthodontic material, but appropriate material selection and indication-specific use remain essential for achieving predictable long-term clinical outcomes.

KEYWORDS - Zirconia, Monolithic Zirconia, Translucency, All ceramics

INTRODUCTION
Advances in materials and clinical applications have evolved dental restorations from metal-ceramic to metal-free ceramic dental restorations. The increased demand for esthetic, durable and biologically acceptable dental restorations has been met with the gradual transition to all-ceramic crowns and bridges. Metal-ceramic restorations have long been the standard of care in aesthetic dentistry due to their strength and longevity; however, several inherent limitations, such as the opaque nature of metal, unaesthetic metal showing through thin porcelain layers, and patients' increasing demand for more natural dental aesthetics, have prompted the introduction of metal-free dental restorations.[1] Zirconia, as an advanced engineering material, has unique mechanical properties, is biocompatible, and has sufficient aesthetic parameters, which have made it the choice of many clinicians and researchers.[2]
Initially used in industrial and orthopaedic applications on account of its high strength and fracture resistance, zirconia was subsequently introduced into the dental field with the advancement of the material science and digital technology. With the progress of prosthodontic science and clinical techniques, its applications have expanded from being used as a framework for veneered porcelain dental restorations to numerous applications such as monolithic crowns and fixed partial dentures, and as implant abutments, posts and frameworks of implant-supported dental prostheses. Its fabrication also became feasible with the advent of CAD/CAM technology, and its clinical application has been strongly supported in terms of precision, reproducibility and efficiency.[2]
Zirconia has gained widespread acceptance and usage in prosthodontics. The mechanical properties include high flexural strength, adequate fracture toughness, and resistance to crack propagation. In terms of aesthetics, while early versions of zirconia were predominantly opaque, subsequent developments in both composition and microstructure have resulted in more translucent materials that are suitable for more demanding locations aesthetically. From a biological perspective, tissue compatibility, plaque affinity, and soft tissue response have all been shown to be favorable, enabling its use in both tooth- and implant-supported indications.[3]
The above mentioned benefits of zirconia crowns, however, are not without some significant limitations. The phenomenon of low-temperature degradation (LTD) or “aging” of zirconia crowns has been recognized as one of the major concerns in their clinical use. Exposure of zirconia crowns to water and thermal cycling has been shown to induce surface

transformation from tetragonal to monoclinic form leading to deleterious effects on their mechanical properties. Veneer chipping of bilayered zirconia restorations is another significant technical problem encountered during clinical use. [2] A major challenge with the use of zirconia crowns is the achievement of an optimal compromise between aesthetics and strength. While increased translucency is perceived to be more aesthetic, it is accompanied by a decrease in mechanical strength. Additionally, cementation and bonding of zirconia crowns remain clinically significant problems due to the lack of interaction of zirconia surface with conventional glass-ceramic surface conditioning agents. Newer translucent as well as multilayered zirconia systems have demonstrated promising results; however, further clinical evaluation is necessary to establish their long-term clinical behavior. [4]

This narrative review aims to critically summarize the material science, processing methods, clinical applications, limitations, and recent advances of zirconia used in prosthodontics.

MATERIALS AND METHODS

Review design

This article is a narrative review that aimed to provide a critical and thematic approach to providing information about zirconia in prosthodontics. Unlike systematic reviews and meta-analyses that aim to solve clinical questions using evidence-based approach by summarizing and quantifying the existing evidence from literary papers using explicit methods, the aim of this review was to provide an overview of published data on the topic that can provide clinically meaningful information about zirconia from the view point of a material scientist, focusing on issues that are relevant to everyday practice of prosthodontics.

Data sources

Literature search was performed on major databases such as PubMed, Scopus, Google Scholar using appropriate key words and relevant phrases. Additionally, all available references from relevant articles found in literature search were manually checked to find any potentially missed studies.[5]

Search strategy

The literature search was performed by combining relevant search terms associated with zirconia and its clinical applications in prosthodontics. The search terms and phrases included in the literature search were: “zirconia in prosthodontics” and “Y-TZP dental ceramics”, “monolithic zirconia”, “zirconia crowns and bridges”, “zirconia implant abutment(s)”, “low temperature degradation of zirconia”, and “bonding to zirconia”. The majority of published studies and articles retrieved were from the years 2000–2025, and some landmark studies and references published prior to 2000 were also included for comprehensive understanding of the topic.[6]

Eligibility approach

This review was restricted to studies published in the English language from 2000 to 2025. All types of studies, such as in vitro, in vivo, clinical studies and review articles relevant to zirconia used in dental practice were included. [7] Both fundamental studies on zirconia and recent studies were selected for this review. Excluded were articles on industrial zirconia, non-dental application, and irrelevant topics. However, preference was given to articles which addressed the clinical relevance in prosthodontics, such as properties, indications, processing, biocompatibility, clinical complications and long-term results.[8]

Data synthesis

The included literature was thematically grouped and narratively synthesized. Instead of conducting quantitative data pooling, the synthesized evidence was organized around major themes addressing the composition and crystal phases, mechanical and optical properties, processing methodology, biological response, clinical applications and limitations, as well as recent advances of zirconia in dental prosthesis fabrication.[9]

RESULTS AND DISCUSSION

Composition and crystal phases of zirconia

Zirconia is presented as a polycrystalline ceramic material consisting of three crystallographic forms: monoclinic, tetragonal, and cubic. Pure zirconia in actual, is monoclinic at room temperature and transforms into the tetragonal phase at elevated temperature and then into the cubic phase at even higher temperatures. For that reason, it is unstable for direct use as a structural dental material unless it is chemically stabilized. There are five different oxides that are commonly used for the stabilization of zirconia, namely yttria, magnesia, calcia, and ceria.[9] Among dental zirconia, yttria-stabilized zirconia is the most commonly used ceramic material due to its balanced mechanical properties. Conventional 3Y-TZP contains approximately 3 mol% yttria, consists mainly of tetragonal phase and exhibits high strength, excellent fracture resistance and good clinical reliability. In pursuit of improved translucency, newer zirconia, 4Y-PSZ and 5Y-PSZ have been developed, which contain increased cubic phase. However, increased yttria content results in improved translucency, but decreased transformation toughening and decreased fracture resistance compared to conventional 3Y-TZP. Therefore, yttria content directly affects phase composition, microstructure, mechanical properties and esthetic characteristics.[10]

Mechanical properties and transformation toughening

Zirconia is one of the hardest and strongest dental ceramic and therefore one of the most common used materials in prosthodontics. Its high flexural strength, adequate fracture toughness, and high resistance to crack propagation has made it an effective material for posterior crowns and onlays, fixed partial dentures, implant abutments and also single crown and multiple units framed by implants and supported by the mucosa.[12] Although initially the early all-ceramic systems were too brittle for posterior use, zirconia has offered Dentists of today a strong, well-tested, metal-free restorative option. [11]

Transformation toughening plays a significant role in the mechanical behavior of tetragonal zirconia. When a crack is propagating through the material, the high stress at the crack tip can promote transformation of the tetragonal to the more dense monoclinic phase. This transformation plasticity causes volumetric expansion ahead of the crack tip resulting in the generation of compressive stresses that effectively arrest or slow down crack propagation.[2] This unique crack-arresting mechanism is not solely dependent on the hardness of the material, as is the case for alumina-based ceramics, and thus accounts for the higher (life) time-based fracture resistance of zirconia. Other factors that affect the mechanical properties of zirconia include grain size, phase content, porosity, alumina content, and sintering conditions. Optimizing microstructural refinement and phase stability is crucial for achieving clinically reliable performance of zirconia. [6]

Optical properties and esthetic behavior

Despite having superior mechanical properties, previous dental zirconia materials exhibited poor optical behavior. From a clinical and esthetic viewpoint, for a restorative material to be considered successful it must have the ability to mimic the highly transparent nature, light transmittance, and optical dimension of natural teeth. [6] Most current dental zirconia generations have high crystallinity, high light scattering and high refractive indices. Due to these optical characteristics, they lack esthetic acceptability for direct implant restorations, however, they can be used as high strength frameworks that are veneered with aesthetically pleasing porcelain (veneered frameworks) primarily in the anterior teeth region.[11]

The optical properties of zirconia can be influenced by several factors including grain size, porosity, alumina content, crystal distribution and volume percentage of tetragonal and cubic phases. [8] The previous studies demonstrated that light scattering occurred at areas where pores, grain boundaries or phase boundaries with different refractive indices interfered with light transmission. In order to achieve better aesthetics, new type of zirconia materials have been developed and these contain higher percentage of cubic phase, lower content of alumina, improved microstructure and multilayered shading. The improved translucency enables usage of zirconia in more esthetic areas. However, better translucency comes at the cost of reduced strength and hardness. Hence, indication-specific usage of zirconia still prevails, where stronger and relatively opaque types are indicated for high-stress posterior indications, and specific highly translucent types can be used in selected aesthetics indications.[12]

Low-temperature degradation and aging

In addition to wear, low-temperature degradation or “aging” of zirconia is a major long-term concern.[33] This phenomenon involves a gradual transformation of the metastable tetragonal phase to the more stable monoclinic phase that occurs over time in the presence of moisture and elevated temperature.[33] Unlike the local, beneficial event of phase transformation that produces transformation toughening, surface transformation of the zirconia phase is detrimental to the long-term performance of the material. [13]

Water penetration into the zirconia in vitro can lead to surface roughening, abraded grain pull-out, micro cracking and a reduction in mechanical strength.[10] Many attempts have been made to reduce low-temperature degradation of ZrO2, including grain size modification, increase of stabilizer content, sintering temperature, and microstructural modification.[19] While an increased percentage of the cubic phase may improve the stability of the material against transformation-induced aging, it simultaneously leads to a loss of transformation toughening.[10] Therefore, hydrothermal stability should be taken into consideration when selecting ZrO2 for clinical use, together with strength and aesthetics. [14]

Biocompatibility and biological response

Zirconia has been widely accepted due to its highly biocompatible nature and its favourable clinical performance as a tooth supported restorations and implants. As a matter of fact, it is chemically stable, corrosion resistant and has excellent biocompatibility that makes it suitable for crowns and fixed partial dentures, implant abutment and frameworks. Moreover, as compared to metal, it has received extensive attention due to excellent biological sealed adaptation with soft tissues and minimum gingival staining. This feature specifically makes it appropriate for aesthetically critical areas and thin gingival biotype patients. [15]

Recently developed zirconia dental restorations exhibit low plaque affinity that may contribute to healthy peri-implant soft tissue.[9] In vitro studies have shown a favorable osteoblast response and biocompatibility that support osseointegration.[14] Although ZrO2 does have a number of advantages over titanium in the biological and esthetic areas, not all indications are suited for this material without further clinical and in vitro research. Ultimately, there are no universal best choices in clinical situations and ongoing evidence supports the continued use of titanium implants. However, from design to clinical outcomes, opposing titanium implant substructures must be tested for efficacy in specific indications to determine where each material has the most solid foundation of evidence. [16]

Processing methods of zirconia

Conventional processing and sintering

The processing route of zirconia has a significant influence on its clinical performance.[2] Present production methods for zirconia typically start by making a powder and then compacting and sintering it into a fully dense, uniform microstructure.[25] It is therefore important that the quality of the powder is consistent and that effective compaction and sintering procedures are used to produce a material with minimal impurities and no internal defects, porosity or agglomerates. Such an incorporated flaw can significantly reduce the life of the clinical performance of this very defect-sensitive material, which is reliant on more than just a correct chemical composition.[17]

II. CAD/CAM milling

The fabrication of zirconia restorations today is mainly performed by CAD/CAM systems, such as CAD/CAM machines for chairside or lap-milling, 3D printing and micro-stereolithography for indirect manufacturing. Digital workflows create new possibilities for prosthetic design, while greatly reducing the variability of manual work, and improving fabrication reproduction. Although CAD/CAM milling is a routine technique, it has its own intrinsic limitations. Many issues can be encountered with material waste, wear of burs, chipping of cutting edges, and mainly machining-induced defects at the surface of milled crowns. While CAD/CAM is the current "state of the art" for zirconia milling, its success greatly depends on many variables including quality of the zirconia blank, milled parameters, and sintering and polishing steps.[18]

III. Sintering protocols and effects on properties

Sintering affects zirconia mechanical properties and has significant effects on the density, grain growth, porosity, dimensional stability, translucency, and reliability. Any defects produced during the green state can remain in the sintered frameworks and compromise their reliability. Subsequently, variations in sintering parameters, including sintering rate, peak temperature, holding time, and cooling rate, potentially affect phase stability and microstructure. Creating shortcuts through the process that can be quickly implemented in the laboratory with seemingly acceptable results is tempting; however, porosity, undesirable grain growth, and decreased long-term strength can be anticipated. Thus, what was once viewed as a straightforward final laboratory step has evolved and is now recognized as a critical process that affects the quality of zirconia frameworks.[19]

IV. Additive manufacturing and 3D printing of zirconia

Advantages of additive manufacturing over traditional milling of dental restorations include design freedom, material efficiency, and production of highly complex geometries. However, current studies on additive manufacturing of zirconia have reported inadequate results, with the primary concerns being excess porosity, inadequate interlayer connection, decreased flexural strength, and less translucency than heavily irradiated milled specimens. [20] However, based on the present data, the highest possible clinical indication for additively manufactured zirconia currently would be for use in experimental, temporary clinical situations, or non-loading situations. However, on the basis of the present data, routine definitive indications are not recommended at this time. Long-term clinical outcomes are yet to be determined. [21]

V. Surface treatment, bonding, and cementation

Clinical bonding to zirconia remains important because the material does not etch with hydrofluoric acid similar to silica-based materials, and alternative surface treatments have been developed to achieve successful bonding. Airborne particle abrasion of zirconia increases surface roughness and provides micromechanical retention, and improvement in chemical bonding to zirconia has been reported with the use of 10-MDP-containing primers in addition to current resin cement systems. [22]

While such methodologies improve bonding, they inherently involve a trade-off, where high bond strength is often countered by compromised tooth structure via over-preparation, or material alteration due to excessive etching leading to embedding of defects. Thus, optimal cementation involves more than simply maximal surface roughening; rather, surface modification must go so far as to facilitate hybridization of the various materials involved, all the while producing the least amount of structural alteration consistent with indications. Indication-specific procedures are therefore of utmost importance.[23]

Clinical applications in prosthodontics

1. Zirconia crowns

Zirconia is a widely used material for full-coverage crowns due to its high strength, moderate esthetics and good biocompatibility.[7] Although used mainly in posterior regions due to higher occlusal loads, improved translucent dental zirconia may be used for selected anterior indications.[24]

2. Fixed partial dentures

In addition to enabling the increased use of all-ceramic systems in posterior and multi-unit situations, of major importance is the increased number of clinical situations in which fixed partial dentures made of zirconia-based ceramics can be indicated. Higher strength relative to many contemporary dental ceramics makes possible the clinical use of zirconia-based CAD-CAM milled copings in fully solid fixed partial dentures, functioning in load bearing situations, either tooth supported or implant supported. [25,26]

3. Monolithic zirconia restorations

The development of monolithic zirconia was aimed at overcoming the problem of chipping experienced with bilayered zirconia restorations.[11] By removing the veneering porcelain, a more reliable restoration has been created.[11] Moreover, increased translucency of more recent zirconia materials has extended the clinical indications for their use; however, case selection is still necessary, as highly translucent grades have reduced fracture strength and increased gorge depth. [26]

4. Zirconia post systems

Zirconia posts offer an esthetic alternative to metal posts. While they have the advantages of optical compatibility with the surrounding ceramic, rigidity and limited retrievability must be taken into account during clinical decision making. [26]

5. Zirconia implant abutments

Zirconia implant abutments are particularly useful in esthetic locations where they eliminate the grey shine-through characteristic of metal abutments and may have a positive effect on the tissues. The biologic advantage of zirconia abutments is largely due to their surface characteristics which do not promote plaque accumulation. [27]

6. Zirconia implants

Zirconia dental implants are an alternative to use of metal (titanium) in dental treatments as they offer biological compatibility, corrosion resistance and also aesthetic advantage of having a tooth like color and translucency. While there are some clinical studies, long term clinical data are limited and more clinical evidences are needed before it becomes a commonly used metal-free alternative to traditional titanium dental implants. [28]

Complications and limitations

Although ZrO2 has several benefits, it has some disadvantageous clinical properties i.e. veneer chipping is one of the most common clinical complications in bilayered ZrO2 restorations. Even though stronger grade ZrO2 has been introduced, it becomes opaque. [7] Highly translucent ZrO2, on the other hand, may comprise its mechanical strength. Moreover, while the LTTD is diminishing as the material shows longer-term hydrothermal stability, adhesive bonding and intraoral repair is more difficult than that with glass-ceramic and requires specific procedures for bonding. In clinical wear, machined highly transparent ZrO2 shows relatively good wear against polished opponent tooth structures, but insufficient polishing and preparation smoothening compromised its clinical wear resistance. Other properties of newer generations of dental ZrO2, additive manufacturing strategies and submicron-grained custom-made zirconia implants and abutments, are supported mostly by in vitro and short-term in vivo evidence, and long-term clinical evidence is lacking. [29]

Recent advances and future directions

There have been developments in zirconia that attempt to make it more esthetic yet still provide the necessary strength and durability. Multilayer zirconia, gradient zirconia, and translucent high-yttria zirconia (THYZ) have improved optical integration and clinical applications. Additionally, better methods of coloring and manufacturing have been developed to make zirconia more esthetic. [30]

Future developments in dental zirconia may require closer collaboration between material scientists and digital dentists. On one hand, improved CAD/CAM software, design optimization software and quality control protocols incorporating AI could revolutionize the workflow for zirconia fabrication and machining. On the other hand, there is ongoing need for research into additive manufacturing to match, for example, the high loads that can be withstood by milled and veneered elatlas® crowns. Furthermore, long-term clinical studies are necessary to clarify the lifetime that can be expected of newer generations of zirconia, of multilayer systems and zirconia implants. [31]

CONCLUSION

Today's modern dental materials consistently evolve to better serve the needs of both dentists and patients, and recent developments in zirconia have been especially impactful in the field of prosthodontics. The material initially was utilized primarily in the dental casting arena due to its toughness, compatibility, and potential esthetic improvements, which has helped Zirconia expand into other areas of fixed and implant prosthodontics. What was initially believed to be a single material has been recognized to include many variations and formulations based on variations in composition, phase content, and processing methodology. [32] This article explores how variations in these properties can cause variations in clinical performance.

Long-term clinical success with zirconia restorations requires the correct choice of zirconia generation for the intended indication.[12] Conventional high-strength zirconia is still indicated for highly stressed areas, whereas new translucent zirconia materials provide optimal aesthetics in specific indications, but offer only limited mechanical reserve.[12] In addition, issues such as low-temperature degradation, bonding, veneering, and the reliability of some newer materials still need critical evaluation. [33]

Zirconia continues to be a highly relevant material in today's prosthodontics, yet its optimal use requires an appropriate choice based on material properties, as well as case–specific indications that are supported by appropriate planning and clinical decisions.

REFERENCES

1. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials. 1999;20(1):1-25.
2. Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater. 2008;24(3):299-307.
3. Al-Amleh B, Lyons K, Swain M. Clinical trials in zirconia: a systematic review. J Oral Rehabil. 2010;37(8):641-652.
4. Heintze SD, Rousson V. Survival of zirconia- and metal-supported fixed dental prostheses: a systematic review. Int J Prosthodont. 2010;23(6):493-502.
5. Özcan M, Bernasconi M. Adhesion to zirconia used for dental restorations: a systematic review and meta-analysis. J Adhes Dent. 2015;17(1):7-26.
6. Linkevicius T, Vaitelis J, Steigmann M, Linkeviciene L, Saulacic N, Sader R. The effect of zirconia or titanium as abutment material on soft peri-implant tissues: a systematic review and meta-analysis. Clin Oral Implants Res. 2015;26 Suppl 11:139-147.

7. Pereira GKR, Venturini AB, Silvestri T, Dapieve KS, Montagner AF, Soares FZM, et al. Low-temperature degradation of Y-TZP ceramics: a systematic review and meta-analysis. J Mech Behav Biomed Mater. 2016;55:151-163.
8. Thoma DS, Sailer I, Ioannidis A, Zwahlen M, Makarov N, Pjetursson BE. A systematic review of the survival and complication rates of resin-bonded fixed dental prostheses after a mean observation period of at least 5 years. Clin Oral Implants Res. 2017;28(11):1421-1432.
9. Zhang Y, Lawn BR. Novel zirconia materials in dentistry. J Dent Res. 2018;97(2):140-147.
10. Pahwa A, Bali Y, Goswami R, Trivedi A. Prosthetic rehabilitation of mucormycosis patient with cast partial definitive obturator. Eur Chem Bull. 2023;12:5831-.
11. Pjetursson BE, Valente NA, Strasding M, Zwahlen M, Liu S, Sailer I. A systematic review of the survival and complication rates of zirconia-ceramic and metal-ceramic single crowns. Clin Oral Implants Res. 2018;29 Suppl 16:199-214.
12. Tabatabaian F. Color aspect of monolithic zirconia restorations: a review of the literature. J Prosthodont. 2019;28(3):276-287.
13. Limones A, Molinero-Mourelle P, Azevedo L, Romeo-Rubio M, Correia A, Gomez-Polo M. Zirconia-ceramic versus metal-ceramic posterior multiunit tooth-supported fixed dental prostheses: a systematic review and meta-analysis of randomized controlled trials. J Am Dent Assoc. 2020;151(4):230-238.e7.
14. Comino-Garayoa R, Cortés-Bretón Brinkmann J, Peláez J, López-Suárez C, Martínez-González A, Suárez MJ. Adhesion to zirconia: a systematic review of surface pretreatments and resin cements. Materials (Basel). 2021;14(11):2751.
15. Gonzaga CC, Cesar PF, Miranda RBP, Yoshimura HN. Do tooth-supported zirconia restorations present more technical failures related to fracture or loss of retention? Systematic review and meta-analysis. Clin Oral Investig. 2022;26(8):5129-5142.
16. Kim W, Kim SJ, Choi J, Bae JH, Park JM. Clinical outcomes of implant-supported monolithic zirconia crowns and fixed partial dentures: a systematic review. J Prosthodont. 2023;32(2):102-107.
17. Rigos AE, Hahnel S, Preis V, Rosentritt M. Zirconia bond strength durability following artificial aging: a systematic review and meta-analysis of in vitro studies. Jpn Dent Sci Rev. 2023;59:138-159.
18. Shihabi S, Alzahrani F, Alhamed M, Kern M. Clinical outcomes of tooth-supported monolithic zirconia vs. porcelain-veneered zirconia fixed dental prosthesis, with an additional focus on the cement type: a systematic review and meta-analysis. Clin Oral Investig. 2023;27(10):5755-5769.
19. Thammajaruk P, Inokoshi M, Chong S, et al. Cleaning methods of contaminated zirconia: a systematic review and meta-analysis. Dent Mater. 2023;39(3):235-245.
20. Dadoo A, Jain S, Mowar A, Bansal V, Trivedi A. 3D printing using CAD technology or 3D scanners, a paradigm shift in dentistry—a review. Int. J. Med. Dent. Res. 2021;1:35-40.
21. Mohseni P, Soufi A, Chrcanovic BR. Clinical outcomes of zirconia implants: a systematic review and meta-analysis. Clin Oral Investig. 2024;28(1):15.
22. Cesar PF, Miranda RBP, Santos KF, Scherrer SS, Zhang Y. Recent advances in dental zirconia: 15 years of material and processing evolution. Dent Mater. 2024;40(5):824-836.
23. Huang B, Chen M, Wang J, Zhang X. Advances in zirconia-based dental materials: properties, classification, applications, and future prospects. J Dent. 2024;147:105111.
24. Ramos RQ, Mercelis B, Ahmed MH, Peumans M, Lopes GC, Van Meerbeek B. Bonding of composite cements containing 10-MDP to zirconia ceramics without dedicated ceramic primer. J Adhes Dent. 2024;26:135-145.
25. da Silva SEG, da Silva NR, Santos JVN, Moreira FGG, Özcan M, de Souza ROA. Accuracy, adaptation and margin quality of monolithic zirconia crowns fabricated by 3D printing versus subtractive manufacturing technique: a systematic review and meta-analysis of in vitro studies. J Dent. 2024;147:105089.
26. Alghauli MA, et al. The physical-mechanical properties of 3D-printed versus conventional milled zirconia for dental clinical applications: a systematic review with meta-analysis. J Mech Behav Biomed Mater. 2024;156:106601.
27. 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.
28. Chmielewski M, Dąbrowski W, Ordyniec-Kwaśnica I. The fracture resistance comparison between titanium and zirconia implant abutments with and without ageing: systematic review and meta-analysis. Dent J (Basel). 2024;12(9):274.
29. Shah N, et al. An evaluation of antagonist enamel wear opposing full-coverage zirconia crowns versus other ceramics full-coverage crowns and natural enamel: an umbrella review. J Indian Prosthodont Soc. 2024;24(3):217-224.
30. Tabarak N, et al. Zirconia-ceramic versus metal-ceramic implant-supported multiunit fixed dental prostheses: a systematic review and meta-analysis. Dent Res J (Isfahan). 2024;21:5.
31. Tajti P, et al. Monolithic zirconia as a valid alternative to metal-ceramic for implant-supported single crowns in the posterior region: a systematic review and meta-analysis of randomized controlled trials. J Prosthet Dent. 2024;132(5):?
[Check final page range before submission]
32. Miura S, Fujita T, Fujisawa M. Zirconia in fixed prosthodontics: a review of the literature. Odontology. 2025;113(2):466-487.
33. Mosaddad SA, et al. Do 3D printed and milled tooth-supported complete monolithic zirconia crowns differ in accuracy and fit? A systematic review and meta-analysis of in vitro studies. J Prosthet Dent. 2025;133(2):383-393.s