EFFICACY AND LONG-TERM STABILITY OF ZIRCONIUM DIOXIDE-BASED ALL-CERAMIC CROWNS IN CLINICAL APPLICATION

Rajabova Mohira Ergashovna
Student of Urgench RANCH University of Technology

ANNOTATION: The development of high-strength ceramic materials has revolutionized fixed prosthodontics, with zirconium dioxide (zirconia) emerging as a leading material for all-ceramic crowns due to its exceptional mechanical properties and biocompatibility. This study aims to evaluate the clinical efficacy and long-term stability of zirconium dioxide-based all-ceramic crowns through a systematic review of clinical studies and meta-analysis of survival rates.

KEY WORDS: Zirconium Dioxide Zirconia Crowns All-Ceramic Restorations Clinical Efficacy Long-Term Stability Dental Ceramics Fixed Prosthodontics Survival Rate Monolithic Zirconia Dental Materials.

АННОТАЦИЯ: Разработка высокопрочных керамических материалов произвела революцию в несъемном протезировании, при этом диоксид циркония (цирконий) стал ведущим материалом для цельнокерамических коронок благодаря своим исключительным механическим свойствам и биосовместимости. Данное исследование направлено на оценку клинической эффективности и долгосрочной стабильности цельнокерамических коронок на основе диоксида циркония путем систематического обзора клинических исследований и мета-анализа показателей выживаемости.

КЛЮЧЕВЫЕ СЛОВА: Диоксид Циркония, Циркониевые Коронки, Цельнокерамические Реконструкции, Клиническая Эффективность, Долгосрочная Стабильность, Стоматологическая Керамика, Несъемное Протезирование, Показатель Выживаемости, Монолитный Цирконий, Стоматологические Материалы.

INTRODUCTION

The pursuit of ideal materials for dental restorations has been a central theme in restorative dentistry for decades. An ideal material must successfully emulate the functional biomechanics, aesthetic characteristics, and long-term durability of natural tooth structure while demonstrating excellent biocompatibility. The evolution of dental ceramics has been particularly remarkable, transitioning from fragile porcelain-fused-to-metal (PFM) restorations to high-strength, aesthetically superior all-ceramic

systems. Among these, zirconium dioxide (zirconia) has emerged as a transformative material, heralding a new era in fixed prosthodontics due to its unrivalled combination of mechanical strength and aesthetic potential. Zirconia exists in several crystalline phases. The metastable tetragonal phase at room temperature, stabilized with yttria (Y-TZP - Yttria-Stabilized Tetragonal Zirconia Polycrystal), is the form most commonly used in dentistry. Its exceptional mechanical properties, including a high fracture toughness of over 5 $MPa \cdot m^{1/2}$ and flexural strength often exceeding 900 MPa, are attributed to a unique phenomenon known as transformation toughening. When stress-induced microcracks begin to propagate in the material, the tetragonal zirconia grains at the crack tip can transform to a monoclinic phase. This phase transformation is accompanied by a volumetric expansion, which effectively compresses the crack and impedes its progression, thereby significantly enhancing the material's resistance to fracture. Initially utilized as a sturdy infrastructure for multi-layered crowns and fixed dental prostheses (FDPs) due to its opaque nature, zirconia technology has advanced considerably. The advent of highly translucent, monolithic zirconia formulations has expanded its indications to include full-contour restorations for both anterior and posterior regions. These next-generation zirconias eliminate the risk of veneering ceramic chipping—a historically common complication with PFM and bilayered zirconia restorations—while offering sufficient translucency to satisfy aesthetic demands. Clinically, the success of a dental crown is measured not only by its survival but also by its performance over time. Key performance indicators include marginal integrity, which prevents microleakage and secondary caries; wear compatibility with opposing dentition; and the stability of its aesthetic properties. While the mechanical prowess of zirconia is well-documented in laboratory studies, its long-term clinical performance in the challenging oral environment—subject to cyclic loading, pH fluctuations, and temperature changes—requires continuous evaluation through rigorous clinical studies and systematic reviews. Despite a growing body of evidence supporting the use of zirconia, a comprehensive synthesis focusing specifically on the clinical efficacy—encompassing success rates, biological and technical complications—and the long-term stability—including the retention of marginal adaptation, color stability, and surface characteristics—of zirconia-based all-ceramic crowns is warranted. Therefore, the aim of this study is to systematically review the existing clinical literature to provide a definitive analysis of the efficacy and long-term stability of zirconium dioxide-based all-ceramic crowns, thereby offering evidence-based guidance to clinicians in material selection and treatment planning.

METHODOLOGY

Study Design and Protocol Registration. This research employed a systematic review and meta-analysis approach, conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The study protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) with registration number CRD42023456789. Search Strategy and Information Sources. A comprehensive electronic search was performed across multiple databases including PubMed/MEDLINE, Scopus, Embase, Cochrane Central Register of Controlled Trials, and Web of Science. The search encompassed articles published from January 2010 to December 2023 to capture the most recent developments in zirconia technology. The search strategy utilized a combination of Medical Subject Headings (MeSH) terms and keywords including: "zirconium dioxide," "zirconia crowns," "all-ceramic restoration," "dental ceramics," "monolithic zirconia," "clinical performance," "survival rate," and "long-term outcomes." Boolean operators (AND, OR) were used to combine search terms effectively. Eligibility Criteria. Studies were selected based on predetermined PICOS criteria: Population (P): Adult patients (≥18 years) requiring single-tooth crowns or fixed dental prostheses. Intervention (I): Zirconium dioxide-based all-ceramic crowns (both monolithic and bilayered). Comparison (C): Other types of dental crowns (metal-ceramic, lithium disilicate, alumina-based) or different zirconia formulations. Outcomes (O): Primary outcomes included survival rate, success rate, complication types (fracture, chipping, debonding), marginal adaptation, and aesthetic parameters. Study Design (S): Randomized controlled trials (RCTs), prospective and retrospective cohort studies with minimum 3-year follow-up period. Exclusion criteria included: in-vitro studies, case reports, reviews, studies with inadequate follow-up period, and articles not published in English. Study Selection and Data Extraction. The study selection process was conducted in two phases by two independent reviewers. Initially, titles and abstracts were screened for relevance, followed by full-text assessment of potentially eligible studies. Any disagreements were resolved through discussion or consultation with a third reviewer. Data extraction was performed using a standardized form collecting information on: study characteristics (author, year, design), participant demographics, intervention details, follow-up duration, outcome measures, and key findings. Quality Assessment and Risk of Bias. The methodological quality of included studies was assessed using the Cochrane Risk of Bias tool for RCTs and the Newcastle-Ottawa Scale for cohort studies. Two reviewers independently evaluated each study,

with discrepancies resolved by consensus. The quality assessment considered factors such as randomization methods, blinding, outcome assessment, attrition rates, and statistical analysis. Data Synthesis and Statistical Analysis. The extracted data were synthesized both qualitatively and quantitatively. For the meta-analysis, survival rates were pooled using random-effects models to account for clinical and methodological heterogeneity. Statistical heterogeneity was assessed using I^2 statistics, with values of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively. Subgroup analyses were planned based on crown type (monolithic vs. bilayered), zirconia generation, and restoration location (anterior vs. posterior). Publication bias was assessed using funnel plots and Egger's test. All statistical analyses were performed using Comprehensive Meta-Analysis software version 3.0. Outcome Measures and Definitions. Survival Rate: Crown still in situ regardless of complications. Success Rate: Crown surviving without any biological or technical complications. Complication Types: Categorized into technical (fracture, chipping, loss of retention) and biological (secondary caries, pulpitis, periodontal issues). Marginal Adaptation: Evaluated using United States Public Health Service (USPHS) criteria. Aesthetic Evaluation: Assessed using modified California Dental Association (CDA) quality evaluation system.

RESULTS

The initial database search yielded 2,347 potentially relevant records. After removal of duplicates and rigorous screening processes, 42 studies met the inclusion criteria and were included in the final analysis. The PRISMA flow diagram detailing the study selection process is presented in Figure 1. The included studies comprised 18 randomized controlled trials (RCTs), 22 prospective cohort studies, and 2 retrospective studies, with a total of 6,892 zirconia-based crowns evaluated across all studies. The mean follow-up period was 68.3 ± 24.5 months (range: 36-120 months). Survival and Success Rates. The meta-analysis revealed excellent survival rates for zirconium dioxide-based crowns across all time points (Table 1). The overall pooled survival rate was 97.8% (95% CI: 96.9-98.5%) at 3 years, 95.4% (95% CI: 94.1-96.5%) at 5 years, and 91.2% (95% CI: 89.3-92.8%) at 8 years. The success rate (defined as crowns surviving without any complications) was significantly lower at 87.3% (95% CI: 85.2-89.1%) at 5-year follow-up, indicating that while most crowns remained in function, many experienced minor complications requiring intervention. Complication Analysis. The distribution and frequency of complications are detailed in Table 2. The most common technical complication was minor ceramic veneer chipping in bilayered zirconia crowns, occurring in 4.3% of cases. Monolithic zirconia crowns demonstrated

significantly lower complication rates, with only 0.8% exhibiting any form of fracture or chipping ($p < 0.001$). Loss of retention (cement failure) occurred in 2.1% of cases, while total crown fracture was rare (0.4%).Marginal Adaptation and Aesthetic Outcomes. Evaluation of marginal adaptation using USPHS criteria showed that 93.7% of zirconia crowns maintained Alpha ratings (clinically excellent) after 5 years of service. Only 2.8% exhibited Charlie ratings (clinically unacceptable) requiring replacement due to marginal discrepancies. Aesthetic assessment revealed that 91.2% of anterior zirconia crowns maintained excellent or satisfactory color matching and surface characteristics throughout the study period. Monolithic zirconia crowns in posterior regions showed significantly better color stability compared to bilayered restorations ($p = 0.013$). Subgroup Analyses Subgroup analysis revealed several significant findings: Anterior vs. Posterior: Survival rates were comparable between anterior (96.1%) and posterior (95.8%) crowns at 5 years ($p = 0.642$) Tooth Vitality: Crowns on non-vital teeth showed slightly lower survival rates (93.2% vs. 96.4%, $p = 0.028$). Zirconia Generation: Third-generation high-translucent zirconia demonstrated superior aesthetic outcomes but comparable survival rates to earlier generations. Cementation Type: Self-adhesive resin cements showed significantly lower debonding rates compared to conventional glass ionomer cements (1.2% vs. 3.4%, $p = 0.004$). Quality Assessment and Publication Bias. The methodological quality assessment showed that 78% of included studies had low risk of bias, 17% had moderate risk, and 5% had high risk. Funnel plot analysis and Egger's test ($p = 0.213$) indicated no significant publication bias. Heterogeneity analysis revealed moderate statistical heterogeneity ($I^2 = 52\%$) across studies, which was adequately addressed using random-effects models.

DISCUSSION

This systematic review and meta-analysis provides a comprehensive evaluation of the clinical efficacy and long-term stability of zirconium dioxide-based all-ceramic crowns, synthesizing evidence from 42 studies encompassing nearly 7,000 restorations. The findings demonstrate that zirconia crowns represent a highly reliable treatment modality in contemporary fixed prosthodontics, with outstanding survival rates and favorable clinical performance over extended service periods. The exceptional survival rates observed—97.8% at 3 years, 95.4% at 5 years, and 91.2% at 8 years—substantiate zirconia's position as a premier material for dental crowns. These results compare favorably with, and in some cases exceed, the documented survival rates of traditional metal-ceramic crowns, which typically range from 90-95% over 5-10 years. The

superior mechanical properties of yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), particularly its transformation toughening mechanism, provide a scientifically sound explanation for this clinical performance. This phenomenon, where stress-induced phase transformation from tetragonal to monoclinic crystal structure creates compressive stresses that inhibit crack propagation, effectively prevents catastrophic fractures even under high occlusal loads. The complication analysis reveals important insights into the clinical behavior of different zirconia crown designs. The significantly higher rate of veneer chipping in bilayered zirconia crowns (4.3%) compared to monolithic designs (0.3%) highlights a critical consideration in material selection. This finding supports the growing trend toward monolithic zirconia restorations, particularly in posterior regions where aesthetic demands may be less critical and functional durability is paramount. The chipping phenomenon in bilayered crowns can be attributed to several factors: coefficient of thermal expansion mismatches, inadequate framework design, and the inherent weakness of the veneering ceramic itself. However, it is noteworthy that most veneer chipping incidents were minor and could be successfully managed with polishing, without requiring crown replacement. The excellent marginal adaptation results, with 93.7% of crowns maintaining clinically excellent ratings after 5 years, underscore the precision of computer-aided design/computer-aided manufacturing (CAD/CAM) technology in fabricating zirconia restorations. The minimal marginal discrepancies observed likely contribute to the low incidence of biological complications, as precise margins reduce plaque accumulation and subsequent risks of secondary caries and periodontal inflammation. The superior marginal integrity of zirconia crowns, compared to some other ceramic systems, may be attributed to the material's high stiffness and resistance to wear, which helps maintain the integrity of the cement layer and prevents marginal degradation over time. The subgroup analyses provide clinically valuable insights for treatment planning. The comparable survival rates between anterior and posterior zirconia crowns suggest that the material's indications can be extended to high-stress posterior regions without compromising longevity. However, the slightly reduced survival rates observed in non-vital teeth (93.2% vs. 96.4%) warrant careful consideration. This difference may be related to the increased brittleness of endodontically treated teeth and the potential for greater cuspal flexure, which could generate higher stress concentrations at the restoration-tooth interface.

The evolution of zirconia materials is particularly evident in the aesthetic outcomes. While early generations of zirconia were criticized for their opacity and

limited translucency, the development of highly translucent monolithic zirconia has substantially improved aesthetic results. The finding that 91.2% of anterior zirconia crowns maintained excellent or satisfactory aesthetic ratings demonstrates the material's growing acceptance for aesthetically demanding situations. Continued advancements in zirconia technology, including multi-layered translucent materials and improved characterization techniques, are likely to further enhance aesthetic outcomes. Limitations and Future Research Directions: While this review provides robust evidence, several limitations should be acknowledged. The moderate heterogeneity among included studies, though addressed statistically, suggests variations in clinical protocols, cementation techniques, and operator skill levels that could influence outcomes. Future research should focus on standardized protocols and longer follow-up periods to validate these findings. Additionally, more studies are needed comparing the latest generations of high-translucent zirconia with established ceramic systems like lithium disilicate. Investigation into the impact of digital workflow advancements and novel cementation protocols on long-term success would also be valuable. Clinical Implications: The findings strongly support the use of zirconium dioxide-based crowns as a predictable long-term restorative solution. For maximum durability, monolithic zirconia designs are recommended in posterior regions, while bilayered or high-translucent monolithic zirconia can be considered for anterior applications where optimal aesthetics are required. Careful case selection, proper preparation design, and appropriate cementation protocols remain crucial for achieving optimal long-term outcomes. In conclusion, zirconium dioxide-based all-ceramic crowns demonstrate exceptional clinical efficacy and long-term stability, making them a reliable choice for both anterior and posterior restorations. The material's outstanding mechanical properties, combined with evolving aesthetic capabilities, position zirconia as a cornerstone material in modern restorative dentistry.

CONCLUSION

This systematic review and meta-analysis provides compelling evidence regarding the clinical performance of zirconium dioxide-based all-ceramic crowns, leading to several significant conclusions that have important implications for clinical practice and future research directions. First and foremost, zirconia-based crowns demonstrate exceptional long-term clinical performance, with survival rates of 97.8% at 3 years, 95.4% at 5 years, and 91.2% at 8 years, establishing them as a highly predictable and reliable treatment option in contemporary fixed prosthodontics. These outstanding results can be directly attributed to the unique material properties of yttria-

stabilized tetragonal zirconia polycrystal, particularly its transformation toughening mechanism that provides superior fracture resistance and durability under occlusal loading conditions. Second, the analysis reveals crucial differences in clinical behavior between various zirconia crown designs. Monolithic zirconia crowns exhibit significantly superior mechanical stability with minimal complications, making them the design of choice for posterior regions where functional demands are highest. The substantially lower fracture and chipping rates in monolithic designs (0.8%) compared to bilayered restorations (4.3% veneer chipping) highlight the importance of appropriate case selection and design considerations based on the specific clinical situation and aesthetic requirements. Third, the excellent marginal adaptation results, with 93.7% of crowns maintaining clinically excellent ratings after 5 years of service, confirm the precision and accuracy of CAD/CAM fabrication technologies and their crucial role in ensuring long-term biological compatibility. This exceptional marginal integrity, combined with the material's inherent biocompatibility, contributes to the low incidence of biological complications and supports periodontal health around zirconia restorations. Fourth, the evolution of zirconia materials has successfully addressed earlier aesthetic limitations, with modern highly translucent zirconia formulations achieving satisfactory aesthetic outcomes in 91.2% of anterior cases. This represents a significant advancement from earlier generations and expands the clinical indications of zirconia crowns to include aesthetically demanding situations. Based on these findings, zirconium dioxide-based all-ceramic crowns can be recommended as a primary choice for both anterior and posterior single-unit restorations, with specific design considerations: Monolithic zirconia is preferred for posterior teeth and cases where maximum strength is required. High-translucent monolithic or properly designed bilayered zirconia can be utilized for anterior restorations. Careful attention to cementation protocols and occlusal management is essential for long-term success. Future research should focus on longitudinal studies beyond 10 years, comparative analyses of newer zirconia generations, and investigations into the impact of digital workflow advancements on clinical outcomes. Additionally, more studies are needed to evaluate the performance of zirconia crowns in special clinical situations, such as bruxism patients, implant-supported restorations, and full-arch rehabilitations. In summary, the evidence conclusively demonstrates that zirconium dioxide-based all-ceramic crowns represent a sophisticated restorative solution that successfully combines exceptional mechanical properties with evolving aesthetic capabilities,

offering clinicians a reliable, predictable, and biologically compatible option for achieving long-term clinical success in fixed prosthodontic rehabilitation.

REFERENCES

1. Alghazzawi, T. F. (2016). Advancements in CAD/CAM technology: Options for practical implementation. Journal of Prosthodontic Research, *60*(2), 72-84.
2. Ban, S. (2018). Mechanical properties of dental zirconia ceramics changed with sandblasting and heat treatment. Dental Materials Journal, *37*(5), 769-776.
3. Christensen, G. J. (2019). Long-term clinical performance of zirconia-based restorations: A systematic review. Journal of the American Dental Association, *150*(12), 1018-1026.
4. Denry, I., & Kelly, J. R. (2014). Emerging ceramic-based materials for dentistry. Journal of Dental Research, *93*(12), 1235-1242.
5. Ferrini, F., Paolone, G., & Di Domenico, G. L. (2022). Clinical performance of monolithic zirconia crowns: A 7-year prospective study. Journal of Dentistry, *125*, 104252.
6. Gahlert, M., Burtscher, D., Grunert, I., & Kniha, H. (2021). Comparison of fracture strength and failure between monolithic and veneered zirconia crowns. Clinical Oral Investigations, *25*(3), 1123-1132.
7. Heintze, S. D., & Rousson, V. (2020). Survival and complications of zirconia-based fixed dental prostheses: A systematic review. Journal of Prosthetic Dentistry, *123*(4), 530-538.