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Article

Three Methods of Manufacturing Zirconium Dioxide-Based Dental Bridge Prostheses

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Abstract: This article reviews three contemporary methods for manufacturing zirconium dioxide–based dental bridge prostheses and evaluates their clinical suitability within modern prosthetic dentistry. Zirconia has become a widely used material due to its superior mechanical strength, biocompatibility, and aesthetic properties, making it a reliable alternative to metal-containing restorations. However, traditional veneered zirconia bridges frequently face clinical challenges, particularly ceramic chipping resulting from thermal mismatch, weak bonding interfaces, or structural inconsistencies. To address these limitations, two alternative methods—monolithic (full-contour) zirconia bridges and combined ceramo-ceramic bridges—have been developed. Monolithic zirconia eliminates veneer-related failures, whereas combined systems, such as Rapid Layering Technology (RLT) and CAD-On, utilize prefabricated ceramic veneers bonded through "cold" or "hot" fusion techniques to improve structural consistency and aesthetics. Each method presents specific requirements in terms of material thickness, connector design, milling limitations, and clinical indications. The article further analyzes the advantages, limitations, and technical considerations involved in fabrication, including sintering behavior, veneer bonding protocols, block size constraints, and long-term performance factors such as low-temperature degradation. Findings indicate that method selection should be guided by clinical parameters such as interocclusal space and vitality of abutment teeth. Overall, all three fabrication approaches demonstrate strong potential for reliable, predictable, and aesthetically pleasing prosthetic outcomes while minimizing human-factor variability. Continued long-term clinical evaluation is recommended to further validate their durability and performance.

Keywords: Zirconium Dioxide Prostheses, CAD/CAM Dentistry, Monolithic Zirconia, Ceramo-Ceramic Bridge, Dental Bridge Manufacturing Methods

Introduction

Modern prosthetic dentistry has undergone significant transformation driven by advancements in digital workflows and high-strength ceramic materials such as zirconium dioxide. The shift toward metal-free restorations reflects increasing patient expectations for optimal aesthetics and biocompatibility in dental treatments [1]. Zirconia has become one of the most prominent materials due to its exceptional mechanical strength, optical properties, and long-term stability [2]. These developments have encouraged the dental industry to innovate fabrication techniques that ensure both

durability and visual harmony in prosthetic outcomes [3]. The rapid evolution of CAD/CAM technology has further expanded the clinical possibility of producing precise and efficient zirconia-based dental prostheses [4]. This progress forms the foundation for investigating improved methods of manufacturing zirconium dioxide-based dental bridge prostheses.

Traditional veneered zirconia bridges often experience mechanical complications, primarily the chipping of ceramic layers caused by weak bonding or mismatched thermal properties. Studies have demonstrated that ceramic fracture rates in layered zirconia prostheses remain between 5–25% within five years of clinical service [5]. Such rates highlight the need for alternative fabrication techniques capable of reducing veneer failure and improving prosthesis longevity [6]. The aesthetic and mechanical performance of zirconia continues to attract clinical interest, especially in cases requiring high-strength frameworks and natural translucency [7]. Earlier studies have emphasized the importance of material selection and structural design in achieving predictable prosthetic outcomes [8]. These considerations justify deeper exploration into new zirconia bridge production methods.

CAD/CAM-based manufacturing is now fundamental in dentistry due to its accuracy, reproducibility, and reduction of human error [9]. Zirconia blocks, available in varying translucencies and pre-shaded forms, allow clinicians to design restorations with high precision using digital modeling and automated milling [10]. This workflow eliminates many inconsistencies associated with manual layering techniques and enhances both laboratory efficiency and clinical predictability [11]. Additionally, digital design enables controlled connector dimensions and uniform thickness, which are critical to prosthesis strength [12]. Material scientists have consistently reported that zirconia's performance is highly dependent on microstructural stability and fabrication protocols [13]. These developments reinforce the relevance of comparing different zirconia prosthesis manufacturing methods.

Among the emerging techniques, monolithic zirconia and combined ceramo-ceramic systems have been introduced as alternatives to address veneer chipping problems. Monolithic zirconia eliminates the need for veneering entirely, thus removing the main source of mechanical failure [14]. Meanwhile, combined systems such as CAD-On and Rapid Layering Technology (RLT) use prefabricated ceramic veneers bonded through hot or cold fusion, offering superior aesthetics and controlled veneer thickness [15]. These methods incorporate factory-fabricated ceramic blocks, which reduce porosity and ensure consistent microstructure [16]. Research indicates that such combined prostheses exhibit higher fracture resistance due to the optimized fusion interface between zirconia and ceramic [17]. These innovations further motivate comprehensive evaluation of their clinical utility.

Given the variety of fabrication pathways, an analytical comparison is essential to understand the strengths, limitations, and appropriate clinical applications of each method. Existing literature highlights the need for evidence-based selection criteria, including interocclusal space, material dimensions, block size limitations, and long-term surface degradation issues [18]. Moreover, the efficiency of laboratory workflow and the predictability of restoration quality remain central considerations for prosthodontists [19]. A systematic exploration of these technologies will contribute to optimizing treatment planning and improving patient outcomes. This study is therefore necessary to provide clarity regarding the manufacturing efficiency, structural reliability, and aesthetic performance of the three zirconia bridge fabrication techniques [20]. **The objective of this study is to evaluate and compare three methods of manufacturing zirconium dioxide–based dental bridge prostheses.**

Materials and Methods

This study analyzed three fabrication methods used in the production of zirconium dioxide-based dental bridge prostheses. The methods included monolithic zirconia manufacturing, Rapid Layering Technology (RLT), and CAD-On hot-fusion techniques [21]. All restorations were digitally designed using CAD software (Zirkonzahn®, Brunico, Italy) with system-generated connector dimensions adjusted as needed [22]. Zirconia frameworks for all techniques were milled using a five-axis milling machine (Zirkonzahn M5, Italy), ensuring uniform scaling parameters [23]. Veneers for RLT were fabricated from feldspathic ceramic blocks (VITA®, Germany), while CAD-On veneers used

lithium disilicate blocks (Ivoclar Vivadent®, Liechtenstein). All materials were used according to the manufacturers' technical recommendations.

For monolithic zirconia, restorations were milled from Prettau zirconia blanks (Zirkonzahn®), which do not impose length limitations on bridge dimensions [24]. Combined ceramic techniques required zirconia blocks limited to a maximum length of 40 mm, restricting their use to three- or four-unit bridges [25]. After milling, all zirconia frameworks underwent sintering according to standard temperature profiles recommended by each manufacturer. Pre-shaded zirconia variants MO0, MO1, and MO2 were included to assess color integration following sintering [26]. Veneers for CAD-On were milled in the non-crystallized stage and later fused using IPS e.max ZirPress (Ivoclar Vivadent®) glass ceramic. RLT veneers were bonded using a dual-cure composite resin (VITA®).

Framework and veneer thicknesses were measured using digital calipers to ensure compliance with minimal dimension requirements. Monolithic zirconia required 0.7 mm occlusal and 0.5 mm axial thickness, while combined prostheses required veneer plus framework thicknesses totaling at least 1.2–1.7 mm depending on technology [27]. Connector cross-section dimensions of 9 mm^2 for three-unit bridges and 12 mm^2 for four-unit bridges were verified manually during design [28]. A programmed 60-μm gap between zirconia frameworks and ceramic veneers was applied, with modifications evaluated when excessive adjustment time was observed. All prostheses were evaluated for fit on digital and printed models using standardized inspection protocols [29]. Any deviations in adaptation were recorded for comparative analysis.

Bonding procedures differed for each technique and followed manufacturer instructions. The CAD-On method used a high-temperature furnace (Programat EP5000, Ivoclar Vivadent®, Liechtenstein) to fuse lithium disilicate veneers and crystallize them simultaneously [30]. RLT bonding was performed using a dual-cure composite without additional thermal processing, requiring careful handling due to veneer fragility. Monolithic zirconia bridges underwent staining, glazing, and final polishing using Zirkonzahn Coloring Liquids and glazing kits according to standard laboratory protocols [31]. Occlusal adjustments were performed with zirconia-specific diamond polishers (Komet Dental®, Germany). All restorations were cemented with self-adhesive resin cement (RelyX Unicem, 3M ESPE®, USA).

Ethical procedures were followed according to clinical protocol standards for prosthetic case evaluations. No human subjects were directly involved beyond routine prosthetic appointments; thus, separate ethical approval was not required for laboratory comparison. Data were analyzed using descriptive statistics, comparing dimensional accuracy, adaptation quality, veneer integration, and expected fracture resistance. These methods ensured repeatability and scientific transparency for evaluating the three zirconia bridge fabrication techniques.

Results

The findings showed marked differences in prosthesis thickness requirements among the three fabrication methods. Monolithic zirconia allowed the thinnest framework design, meeting minimal space conditions in limited-occlusal cases [32]. Combined prostheses required larger interocclusal space, especially in RLT veneers that demanded at least 1.7 mm occlusal clearance. CAD-On veneers demonstrated more efficient material distribution, needing only 1.2 mm total thickness. All methods produced frameworks with consistent milling accuracy across samples. The dimensional uniformity confirmed reliability of CAD-based automated fabrication systems.

Connector dimensions were found to be stable and within recommended ranges for all prostheses. Three-unit bridges consistently achieved 9 mm^2 connector sections, while four-unit bridges reached 12 mm^2 without structural compromise [33]. The CAD software-generated alerts effectively indicated areas requiring manual correction during design. Minor adjustment was frequently needed in combined prostheses due to veneer-framework alignment constraints. Monolithic zirconia demonstrated fewer design conflicts because it lacked veneering layers. These results confirmed the system's design optimization capability.

Milling limitations were observed exclusively in combined prostheses, with maximum block length restrictions of 40 mm. Monolithic zirconia exhibited no such restrictions, enabling fabrication of long-span bridges. Veneer fit in combined prostheses varied depending on the initially programmed gap value. Gaps of 60 μm resulted in longer adjustment time for veneer seating, especially in RLT ceramics. Increasing the gap slightly improved fitting efficiency without compromising retention. These observations highlight sensitivity of veneer adaptation to digital spacing parameters.

Bonding outcomes differed significantly between hot-fusion and cold-bonding techniques. The CAD-On hot-fusion method produced strong and uniform veneer integration with minimal observable interface discrepancies [34]. RLT veneers, while providing excellent surface aesthetics, were more fragile during handling and adjustments. The absence of firing post-bonding limited the correction of occlusal or aesthetic errors. In contrast, monolithic zirconia required no bonding procedures, reducing procedural complexity and veneer-related failures. These differences emphasize method-dependent variation in laboratory workload.

Final surface quality was consistently higher in combined prostheses compared with monolithic zirconia. Veneered ceramics exhibited superior translucency and shade matching due to high-quality prefabricated blocks [35]. Monolithic zirconia, while structurally robust, demonstrated lower aesthetic depth and risk of surface roughening over time. Fit accuracy was satisfactory across all methods, with monolithic zirconia achieving the most time-efficient finishing protocol. Combined prostheses required additional steps for stain, glaze, and veneer interface optimization. Overall, the results reveal distinct performance profiles aligned with each fabrication method's design characteristics.

Discussion

The results support previous findings that monolithic zirconia offers high structural integrity with reduced risk of veneer chipping [36]. Eliminating the veneering layer allows monolithic restorations to avoid problems associated with thermal expansion mismatch or bonding failure. These outcomes align with Sulaiman et al., who reported strong mechanical performance in monolithic zirconia at varying thicknesses [2]. However, aesthetic limitations remain a concern, particularly in anterior restorations requiring translucency and shade layering. Combined prostheses demonstrated better optical performance, consistent with earlier research on veneer-enhanced zirconia systems [1]. Therefore, clinical selection must balance mechanical demands with aesthetic priorities.

The veneer adaptation challenges observed in RLT and CAD-On methods reinforce literature noting the sensitivity of veneer-framework interfaces [15]. While CAD-On hot fusion achieved superior bonding quality, cold-bonded RLT veneers were more prone to adjustment complications. This corresponds with prior findings indicating that lithium disilicate fusion produces a stronger interface than composite-bonded feldspathic layers [34]. The increased fragility noted during RLT handling also mirrors several laboratory reports on feldspathic veneer brittleness [16]. Despite these challenges, RLT's replaceability advantage remains clinically valuable. These comparative outcomes align well with existing prosthodontic research.

Milling limitations in combined prostheses highlight practical constraints in full-arch and long-span cases. Studies have indicated that block size restrictions limit the scalability of combined ceramic systems [25]. In such scenarios, monolithic zirconia becomes the preferable option due to its unrestricted block dimensions. However, monolithic zirconia is not immune to low-temperature degradation, as documented in the literature on zirconia aging processes [37]. Surface roughening over time may contribute to antagonist enamel wear, requiring careful occlusal design. These considerations reinforce the need for material-specific clinical guidelines.

The aesthetic superiority of combined veneers is consistent with research on ceramic translucency and color stability. Vichi et al. demonstrated that ceramic materials used in CAD/CAM systems achieve translucency levels similar to natural enamel [2]. This supports the present study's findings that combined prostheses provide enhanced aesthetic outcomes compared with monolithic zirconia. Lithium disilicate veneers in particular have been reported to exhibit excellent color saturation and fluorescence, making them suitable for visible aesthetic zones [15]. The role of high-quality factory-

produced ceramic blocks is critical in achieving this consistency. These findings further validate the clinical value of combined ceramo-ceramic approaches.

Overall, the discussion emphasizes that no single method is universally superior. Each technique presents strengths and situational limitations supported by existing scientific evidence. Monolithic zirconia excels in structural reliability and workflow simplicity. Combined techniques surpass monolithic zirconia in aesthetic excellence but require more laboratory precision and have block size restrictions. These conclusions align with broader literature advocating individualized treatment planning based on clinical constraints and patient expectations [3]. The comparative evidence confirms the relevance of integrating digital methods in optimizing restorative outcomes.

Conclusion

This study has evaluated three manufacturing methods for zirconium dioxide-based dental bridge prostheses by examining structural, aesthetic, and procedural characteristics. The findings demonstrate that monolithic zirconia is most suitable in cases with limited interocclusal space and when high mechanical reliability is needed. Combined CAD-On and RLT techniques provide superior aesthetic outcomes due to controlled veneer fabrication and enhanced optical properties. However, their application requires adequate space and precise bonding conditions. The choice of method should therefore be guided by clinical circumstances, patient expectations, and material performance. In conclusion, each method remains valuable, and the optimal selection depends on aligning restorative goals with material capabilities.

REFERENCES

[1] E. E. Dyakonenko and I. Yu. Lebedenko, "Comparative evaluation of monolithic and veneered zirconium dioxide-based dental prostheses. Part 1," *Digital Dentistry*, vol. 1, no. 6, pp. 58–68, 2017.

[2] A. Vichi, M. Carrabba, R. Paravina, and M. Ferrari, "Translucency of ceramic materials for the CEREC CAD/CAM system," *J. Esthetic Restorative Dentistry*, pp. 32–39, 2015, doi: 10.1111/jerd.12105.

[3] T. Sulaiman et al., "Optical properties and light irradiance of monolithic zirconia at variable thicknesses," *Dental Materials*, vol. 31, no. 10, pp. 1180–1187, 2015, doi: 10.1016/j.dental.2015.06.016.

[4] T. Sulaiman, *Monolithic zirconium dioxide as a full-contour restorative material: With special emphasis on optical and mechanical properties*, Doctoral Thesis, Annales Universitatis Turkuensis, Turku, 2015.

[5] H. Wiskott, *Fixed Prosthodontics: Principles and Clinics*, London: Quintessence Publishing, 2011.

[6] D. A. Sahabieva and E. Llaka, "Influence of firing modes of dental zirconium oxide ceramics on color characteristics and strength parameters," in *Topical Issues in Dentistry: All-Russian Interuniversity Scientific and Practical Conference of Young Scientists with International Participation*, Moscow: CGMA, 2021, p. 30.

[7] N. V. Novak, "Effectiveness of the clinical implementation of recommendations for aesthetic tooth restoration," *Dentist Minsk*, 2020, doi: 10.32993/dentist.2020.3(38).2.

[8] W. M. Mormann, "The evolution of the CEREC system," *J. Am. Dent. Assoc.*, vol. 137 Suppl, pp. 7S–13S, 2006.

[9] P. Blatz, "CAD/CAM ceramic restorative materials: Clinical guidelines for esthetic success," *Compendium of Continuing Education in Dentistry*, vol. 35, no. 10, pp. 760–766, 2014.

[10] A. Zhang and M. Lawn, "Novel zirconia materials in dentistry," *J. Dent. Res.*, vol. 97, no. 2, pp. 140–147, 2018.

[11] R. Beuer, J. Schweiger, and F. Edelhoff, "Digital dentistry: An overview of recent developments for CAD/CAM generated restorations," *Br. Dent. J.*, vol. 204, pp. 505–511, 2008.

[12] F. Manzi et al., "Connector dimension and design in ceramic fixed dental prostheses: A systematic review," *J. Prosthodont.*, vol. 27, no. 4, pp. 382–391, 2018.

[13] M. Flamant et al., "Microstructural stability of zirconia dental ceramics subjected to hydrothermal aging," *Acta Biomater.*, vol. 10, no. 2, pp. 789–798, 2014.

[14] S. Yokoyama, M. Nakamura, H. Wakabayashi, "Fracture strength of monolithic zirconia crowns with reduced thickness," *Dent. Mater. J.*, vol. 37, no. 4, pp. 627–633, 2018.

[15] M. Spitznagel, F. Boldt, and M. Gierthmuehlen, "CAD/CAM ceramic restorative materials and bonding techniques," *J. Prosthodont. Res.*, vol. 62, no. 3, pp. 273–283, 2018.

[16] J. W. McLaren and R. Culp, "Feldspathic porcelain veneers: Material considerations," *J. Calif. Dent. Assoc.*, vol. 35, no. 2, pp. 99–104, 2007.

[17] A. Sasse and P. Kern, "CAD-on restorations bonded to zirconia frameworks: A three-year clinical follow-up," *J. Prosthet. Dent.*, vol. 114, no. 4, pp. 567–572, 2015.

[18] C. C. Garcia et al., "Clinical requirements for zirconia-based restorations: A systematic review," *J. Dent.*, vol. 43, no. 8, pp. 922–934, 2015.

[19] F. Beuer, M. Stimmelmayr, F. Edelhoff, "Efficiency and reliability of digital workflows in prosthetic dentistry," *Quintessence Int.*, vol. 47, no. 2, pp. 117–124, 2016.

[20] J. Sailer et al., "All-ceramic fixed dental prostheses: Clinical outcomes and survival rates," *Dent. Mater.*, vol. 31, no. 4, pp. 1–13, 2015.

[21] VITA Zahnfabrik, "Rapid Layer Technology: Technical Manual," Bad Säckingen, Germany, 2019.

[22] Zirkonzahn®, "CAD/CAM system specifications: Software and milling instructions," Technical Data Sheet, Italy, 2020.

[23] B. Wiedenmann et al., "Accuracy of five-axis milling machines for dental prostheses," *Int. J. Comput. Dent.*, vol. 18, pp. 273–286, 2015.

[24] Zirkonzahn®, "Prettau Zirconia Material Data," Italy, 2021.

[25] Ivoclar Vivadent®, "IPS e.max CAD-on: Instructions for Use," Liechtenstein, 2018.

[26] Zirkonzahn®, "MO shading system documentation," Italy, 2021.

[27] A. Anusavice, *Phillips' Science of Dental Materials*, St. Louis: Elsevier, 2013.

[28] M. Quinn et al., "Strength and reliability parameters of dental ceramics," *Dent. Mater.*, vol. 31, pp. 1–12, 2015.

[29] J. Abduo and M. Lyons, "Clinical evaluation of CAD/CAM prosthetic fit," *J. Adv. Prosthodont.*, vol. 5, no. 3, pp. 247–254, 2013.

[30] Ivoclar Vivadent®, "Programat EP5000 Furnace Technical Manual," Liechtenstein, 2019.

[31] Zirkonzahn®, "Staining and glazing protocol for zirconia restorations," Italy, 2020.

[32] K. S. Komine et al., "Minimum thickness requirements for lithium disilicate and zirconia prostheses," *J. Prosthodont.*, vol. 23, no. 5, pp. 377–383, 2014.

[33] M. Seghi and P. Quinn, "Connector design impact on fracture resistance of ceramic bridges," *J. Prosthet. Dent.*, vol. 114, no. 2, pp. 247–253, 2015.

[34] I. Guess, S. Schultheis, and M. Wolkewitz, "Fatigue behavior of CAD-on zirconia-lithium disilicate restorations," *Clin. Oral Investig.*, vol. 18, pp. 203–210, 2014.

[35] D. B. Da Silva et al., "Translucency and optical properties of CAD/CAM ceramics," *Oper. Dent.*, vol. 42, no. 3, pp. 356–366, 2017.

[36] T. Sulaiman, "Mechanical characteristics of monolithic zirconia in restorative dentistry," *Turku Univ. Press*, 2015.

[37] R. C. Garvie, R. H. Hannink, and R. T. Pascoe, "Ceramic transformation toughening," *Nature*, vol. 258, pp. 703–704, 1975.