An in Vitro Comparative Analysis of Marginal Integrity and Surface Roughness Between Novel 3d Printed Ceramic and Milled Zirconia Crowns

Mehtab S Sidhu1 , M.Keerthika1,a)

1Sidhu Health Centre, New Delhi, India

**Corresponding Author:** a)[karunamoorthysahana0@gmail.com](mailto:karunamoorthysahana0@gmail.com)

**Abstract:** This study aims to compare the marginal integrity and surface roughness of 3D-printed ceramic in comparison to zirconia-milled crowns across different stages, including pre- and post-polishing. The study evaluates the marginal fit and surface roughness of each crown type to determine their suitability for long-term dental restorations.A first maxillary molar typodont tooth was duplicated in epoxy resin, and crowns were fabricated using 3D-printed ceramic and zirconia-milling techniques. Surface roughness (Ra) measurements were taken at post production, pre and post-polishing using a polishing paste. Marginal fit assessment was done using Stereomicroscope. Statistical analyses were conducted to compare the results between ceramic and zirconia crowns. Printed ceramic crowns exhibited a higher initial surface roughness (Ra ~3.5 µm) compared to milled ceramic crowns (Ra ~1.2 µm). However, printed ceramic crowns achieved a smoother surface post-polishing (Ra ~0.2 µm) than milled zirconia crowns. Overall milled zirconia crowns had a better marginal fit as compared to 3D printed ceramic crowns.Zirconia crowns outperform ceramic crowns in terms of marginal fit and surface smoothness, making them a superior choice for long-term posterior restorations. However, 3D-printed ceramic crowns offer flexibility and ease of customization, making them suitable for temporary or anterior restorations. This study reinforces zirconia’s role as the preferred material for permanent, load-bearing restorations, while 3D-printed ceramic shows promise for less demanding applications and provisional restorations.

**Keywords**: Surface roughness, marginal fit, 3D-printed ceramic, zirconia crowns

# INTRODUCTION

The continuous evolution of digital dentistry has transformed the landscape of dental restorations, introducing advanced materials and techniques that enhance both patient outcomes and clinical workflows. The integration of 3D printing technologies and CAD/CAM systems has provided practitioners with new opportunities to deliver high-quality, customized restorations while also streamlining processes in dental laboratories.[(Branco et al., 2023)](https://paperpile.com/c/wISCT7/Bl6M) Among the prominent materials at the forefront of these advancements are 3D printed ceramics and zirconia, each with distinct mechanical and aesthetic properties that make them suitable for various dental applications. Zirconia has established itself as a durable, versatile material for milled crowns, widely acknowledged for its mechanical strength, biocompatibility, and excellent resistance to wear, making it particularly suited for withstanding the high forces encountered in the oral cavity.[(“3D-Printed versus Conventionally Milled Zirconia for Dental Clinical Applications: Trueness, Precision, Accuracy, Biological and Esthetic Aspects,” 2024)](https://paperpile.com/c/wISCT7/HFrQ) On the other hand, the development of 3D printed ceramics, such as OnX Nanoceramic hybrid (SprintRay, LosAngeles, USA), presents an innovative alternative with potential advantages in customization, production speed, and material efficiency, aligning well with the growing demand for precision and personalization in dental restorations[(Gautam et al., 2016)](https://paperpile.com/c/wISCT7/RgYm)The quest to compare 3D printed ceramics with zirconia milled crowns has sparked considerable interest in the field, as these materials offer promising alternatives for restorative procedures. [(G. & Ganapathy, 2022; I. L. Kumar & Ramesh, 2021)](https://paperpile.com/c/wISCT7/v3VAS+3oIpO)) While traditional zirconia milling remains popular, especially for crowns that require high strength and durability, the newer 3D printed ceramic materials bring their own benefits, including the ability to fabricate restorations more rapidly and with a higher degree of design flexibility.[(“The Physical-Mechanical Properties of 3D-Printed versus Conventional Milled Zirconia for Dental Clinical Applications: A Systematic Review with Meta-Analysis,” 2024; Walia et al., 2018)](https://paperpile.com/c/wISCT7/6htw+oEq9) Although studies have evaluated the physical and chemical properties of each material separately, direct comparisons in the context of practical parameters—such as surface roughness and marginal fit are still in their early stages. [(*Evaluation Composite Restoration Posterior Teeth Proanthocyanidin Pretreatment Liner Using Fédération Dentaire Internationale Criteria: Split-Mouth Randomized Controlled Trial*, n.d.; Pranati et al., 2021; Sakthi, 2021)](https://paperpile.com/c/wISCT7/Dla1u+npjru+eBVTs)) Understanding these properties is critical to making informed choices about material selection for crowns, as both surface roughness and marginal fit directly impact the material’s longevity, functionality, and aesthetics in a clinical setting.[(Dewan, 2023)](https://paperpile.com/c/wISCT7/vFqo)Surface roughness is a key factor in assessing the performance of dental materials. A material’s surface texture influences several aspects of its behavior in the oral environment, from its resistance to plaque accumulation to its interaction with surrounding tissues.[(Keerthana & Ramesh, 2021; Murugesan, 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/wISCT7/WcNkc+YlV2h+XXU9N)[(Keerthana & Ramesh, 2021; Murugesan, 2021; Subramanian et al., 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/wISCT7/WcNkc+YlV2h+XXU9N+NkxBW) Research indicates that smoother surfaces contribute to better hygiene as they discourage bacterial adhesion, thus lowering the likelihood of secondary caries and periodontal disease.[(Refaie et al., 2023)](https://paperpile.com/c/wISCT7/oNmvg) [(“Mechanical Characteristics of Zirconia Produced Additively by 3D Printing in Dentistry - A Systematic Review with Meta-Analysis of Novel Reports,” 2024)](https://paperpile.com/c/wISCT7/Tqnw)Zirconia crowns are often highly polished or glazed to achieve smooth surfaces, enhancing their biocompatibility and ease of maintenance for patients.[(Kasabwala et al., 2021; Rajeshkumar & Lakshmi, 2021; Varghese et al., 2023)](https://paperpile.com/c/wISCT7/ucj5k+k3MXk+MeA7A) However, surface roughness can be affected by the conditions within the oral cavity, which are often challenging due to factors like temperature fluctuations, masticatory forces, and chemical exposure. Acidic foods and beverages, for instance, can lower the oral pH and expose dental materials to demineralizing conditions.[(Zandinejad et al., 2019)](https://paperpile.com/c/wISCT7/4Tqj) For 3D printed ceramics, it remains uncertain how exposure to acidic environments affects surface integrity, particularly given that 3D printed materials typically have a more complex microstructure than traditionally milled ceramics.[(Uçar et al., 2019)](https://paperpile.com/c/wISCT7/Cbbr)Dental crowns' long-term prognosis is influenced by various factors, including marginal fit, which can cause clinical failure [[(Chadwick, 2001)](https://paperpile.com/c/wISCT7/ClS1)]. A marginal gap refers to the vertical distance between the finish line of the preparation and the cervical edge of the restoration [[(Pilecco et al., 2025)](https://paperpile.com/c/wISCT7/VwBE)]. A stereomicroscope can be used to measure the space between the crown margin and the finish line under high magnification [[(Dudley & Farook, 2025)](https://paperpile.com/c/wISCT7/vqnO)]. Poor marginal adaptation can cause plaque accumulation, microleakage, recurring caries, and periodontal disease . A marginal gap of 50-120 µm is regarded clinically acceptable . Marginal fit is critical for the success of dental crowns, as degradation can lead to prosthesis failure[(Rosli et al., 2025)](https://paperpile.com/c/wISCT7/UGQK).This study addresses the need for comparative data by evaluating the marginal fit and surface surface of 3D printed ceramics, using OnX as a representative material, and contrasting it with that of zirconia milled crowns.The assessment of these two properties- marginal fit and surface roughness - holds significant implications for the success of dental restorations in the oral cavity. Dental materials must withstand a range of environmental challenges, from mechanical wear to chemical exposure. [(Ramakrishnan et al., 2023; Shenoy & Maiti, 2023; J. S. Sindhu et al., 2023)](https://paperpile.com/c/wISCT7/btKtP+8KDON+CfdEK) Surface roughness not only impacts aesthetics but also affects wear resistance and the ease with which patients can maintain proper oral hygiene. Crowns with rougher surfaces tend to trap more plaque and are associated with increased bacterial colonization, which can lead to complications such as gum inflammation and secondary decay.[(Ercoli & Caton, 2018)](https://paperpile.com/c/wISCT7/jmGg) Marginal fit, meanwhile, is essential for all dental restorations, as it directly influences the longevity of the restoration. [(Dharman et al., 2023; S. Sindhu et al., 2023; Sreenivasagan et al., 2023)](https://paperpile.com/c/wISCT7/hhX5Q+6rhlq+ERMmX) This study aims to fill an important gap in the literature by providing a comparative analysis of 3D printed ceramics and zirconia milled crowns with respect to marginal fit and surface roughness. The findings of this study will assist clinicians in making evidence-based judgments when selecting materials for dental restorations, balancing aesthetic and functional criteria to produce the best possible patient results. Furthermore, the findings will add to the larger body of information on digital dental materials, helping us grasp the possibilities and limitations of new-generation 3D printed ceramics in comparison to well-established zirconia. As digital dentistry evolves, the findings of this study will serve as a platform for future research, allowing for more informed applications of sophisticated materials in clinical practice and encouraging the creation of novel solutions to satisfy the different demands of dental patients.

# MATERIALS AND METHODS

The methodology for evaluating the marginal fit and surface roughness of SprintRay 3D-printed ceramic and zirconia milled dental crowns involved distinct testing phases to ensure a thorough comparison between the two materials.

## Materials

In this study , prepared first maxillary molar was duplicated in epoxy resin to create consistent replicas of the reference tooth. These replicas were then used as a standardized base for designing crowns in both ceramic and zirconia, facilitating a controlled comparative analysis of marginal fit and surface roughness between the two crown materials. Two types of dental crowns, SprintRay 3D-printed ceramic and zirconia milled, were selected for testing. A total of 20 samples (n=20) was taken, with each material group undergoing identical preparation and testing conditions. The 3D-printed ceramic crowns were fabricated using the SprintRay 3D printing system, which utilizes a resin-based ceramic composite, while the zirconia crowns were produced through CAD/CAM milling from yttria-stabilized zirconia blocks, known for high fracture toughness and durability.

A group of yellow objects

Description automatically generated A group of ice cubes

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**FIGURE 1**- Fabrication of Epoxy resin based die

A close-up of a face

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**FIGURE 2:** Digital desgining and fabrication of crowns

Methods

## Marginal Fit Testing

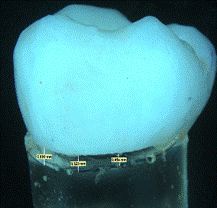
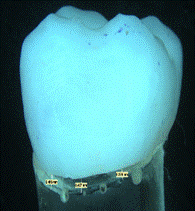
Marginal fit was measured using a stereomicroscope (Leica M205 C, Switzerland) with digital camera (K3) at 16x magnification. Calibration protocols for microscopes were properly followed before beginning measurements. Holmes et al. [18] presented the criteria for determining the vertical marginal gap, which is defined as the distance between the crown margin and the finish line preparation edge. For standardisation, readings for each sample were taken at 3 points- mesiobuccal, mid buccal and distobuccal region. Using this protocol, 3 readings were taken for all 20 samples.

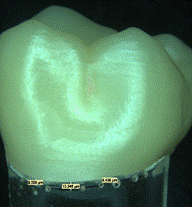
A microscope and a monitor

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**FIGURE 3:**Stereomicroscope used for the study

 A close-up of a tooth

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**FIGURE 4**:Readings measured on the samples

## Surface Roughness Testing

Surface roughness was measured pre and post polishing after using a polishing paste(Prevest). Initial measurements were taken using a stylus profilometer (Mitutoyo SJ-310), which quantifies surface texture by tracing the material surface with a fine stylus. Baseline roughness values were recorded for all samples before polishing. Post polishing readings were measured with the same stylus profilometer to identify any changes in surface texture.

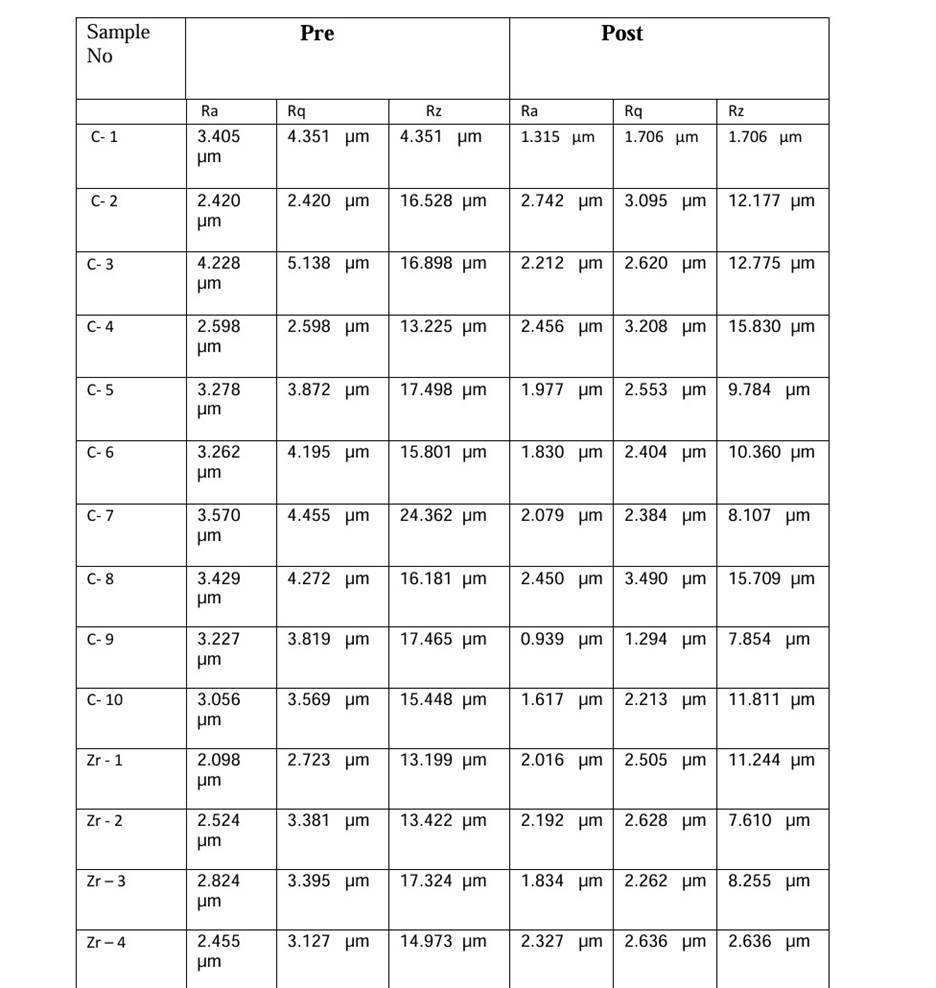


**FIGURE 5:** Stylus Profilometer (Mitutoyo SJ-310) used for measuring surface roughness

# Data Analysis

The pre- and post polishing surface roughness measurements, along with the marginal fit results, were statistically analyzed using appropriate tests (e.g., t-tests – paired and independent). All statistical analyses were conducted using statistical software (SPSS 2023) with a significance threshold set at p < 0.05.

# RESULTS



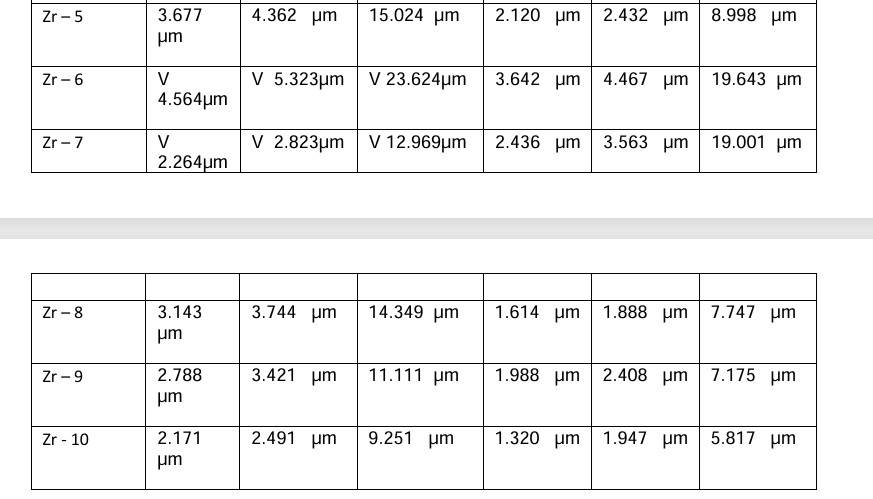


Figure 6: Results

## Surface Roughness Analysis

The surface roughness (Ra, Rq and Rz) values of ceramic and zirconia crowns were evaluated across different treatment stages, including pre-polishing and post-polishing. This allowed for a comprehensive understanding of how each material responds to surface modifications.

## Pre-Polishing Surface Roughness (Ra, Rq, Rz)

The initial surface roughness of ceramic and zirconia crowns was measured before any polishing treatment.

● Ceramic Crowns: The 3D printed ceramic crowns exhibited a higher initial surface roughness ranging from 2.4- 24.9 µm.

● Zirconia Crowns: milled Zirconia crowns demonstrated a slightly lesser initial surface roughness, ranging from 2.0 – 23 µm.

## Post-Polishing Surface Roughness (Ra, Rq, Rz)

Following polishing with Provest polishing paste, both types of crowns showed a significant reduction in surface roughness. Polishing helped smooth the surfaces, improving both aesthetics and functional properties.

● Ceramic Crowns: The surface roughness of 3D printed ceramic crowns decreased substantially post-polishing, showing a value of 1.3- 17 µm.

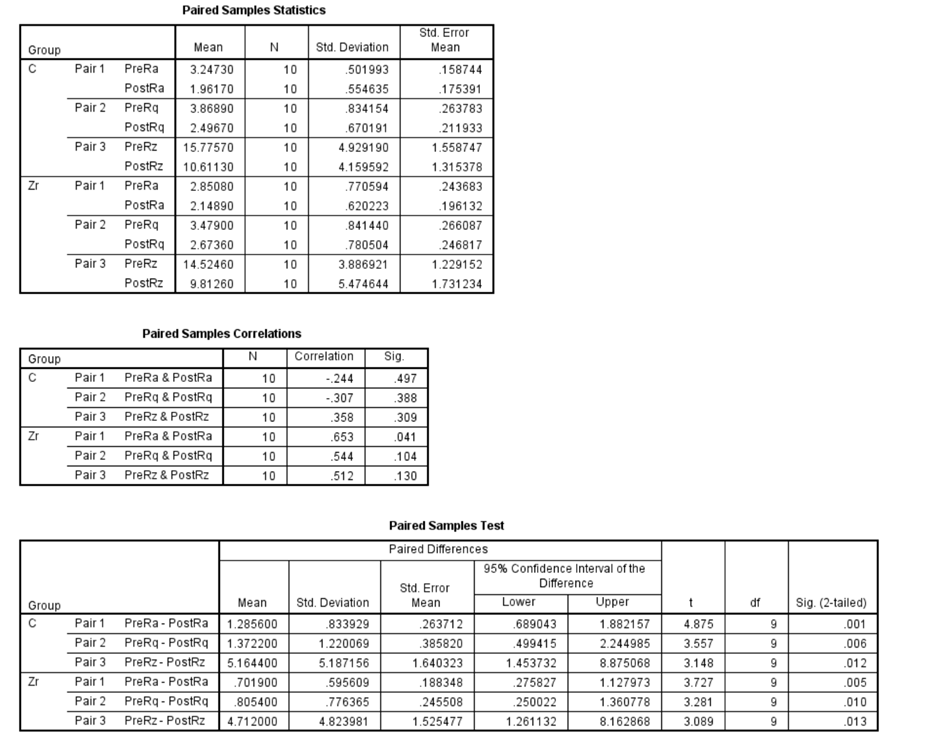
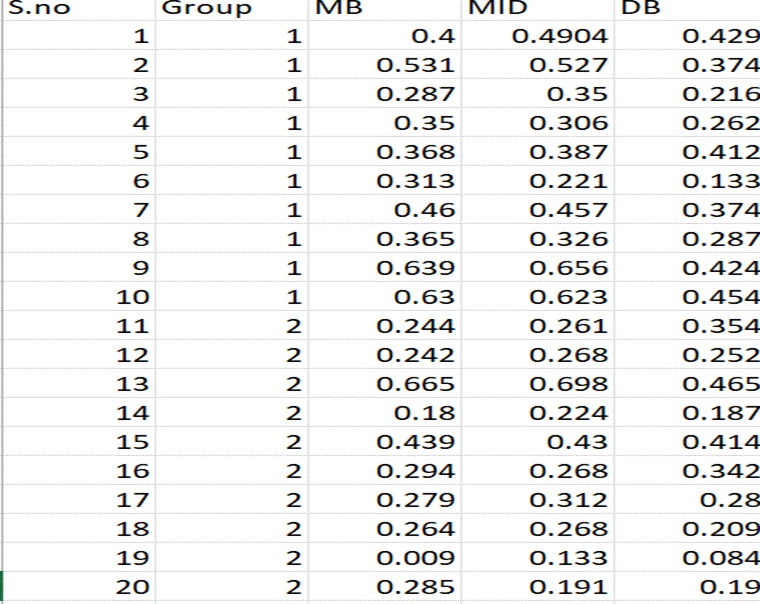
● Zirconia Crowns: Milled Zirconia crowns exhibited an even lower post-polishing values ranging from 1.2 – 11 µm .

Figure 7: Post-Polishing Surface Roughness (Ra, Rq, Rz)

## arginal Fit



**Figure 8:** 3D printed ceramic crowns Group 2- Milled Zirconia crowns

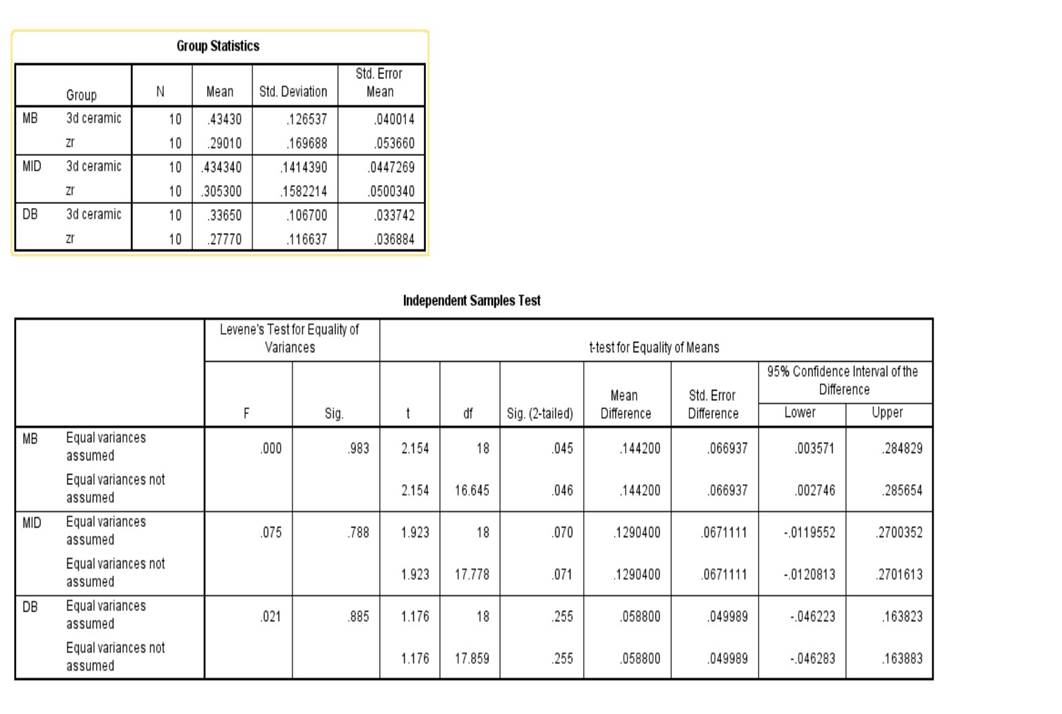


Figure 9: tables

## Marginal fit using Stereomicroscope

3D printed crowns had a marginal gap ranging from 0.28-0.0.65 mm, whereas milled zirconia crowns had a lesser marginal gap ranging from 0.009-0.66 mm.

## DISCUSSION

The comparative analysis of marginal fit and surface roughness between 3D-printed ceramic and zirconia-milled crowns provides valuable insights into their performance in dental restorations. Zirconia, known for its high mechanical strength and resistance to wear, has been a favored material in restorative dentistry for permanent crowns, particularly in load-bearing areas.[(“Longevity and Risk Factors of CAD-CAM Manufactured Implant-Supported All-Ceramic Crowns - A Prospective, Multi-Center, Practice-Based Cohort Study,” 2024)](https://paperpile.com/c/wISCT7/EK2rS) Research indicates that zirconia's hardness and crystalline structure contribute to its ability to withstand high masticatory forces, exceeding 3000 N, which is significantly greater than the typical maximum force tolerance of 3D-printed ceramic crowns, capped around 1600 N. This strength allows zirconia to perform well under occlusal stress, making it a highly recommended choice for posterior restorations where forces are highest.[(Park et al., 2020)](https://paperpile.com/c/wISCT7/jKkA) Previous studies , support this finding, reporting that zirconia crowns withstand compressive stresses up to 1200 MPa, showcasing durability beyond the capacity of many ceramic materials commonly used in restorative applications.[(“Fracture Toughness, Work of Fracture, Flexural Strength and Elastic Modulus of 3D-Printed Denture Base Resins in Two Measurement Environments after Artificial Aging,” 2024)](https://paperpile.com/c/wISCT7/YAAO)The initial surface roughness of the crowns offers insight into how they interact with the oral environment. For 3D-printed ceramic crowns, initial roughness was 2.4- 24.9 µm., which is higher than the2-23 µm recorded for milled zirconia crowns pre-polishing. This lower initial roughness in milled ceramics may be attributed to the milling process. Zirconia's initial rougher texture stems from its density and milling process, where micro-texture differences arise due to the hardness of the material and the milling burr interaction. Zirconia’s hardness makes it amenable to polishing, as seen in this study, where post-polishing Ra values for zirconia were reduced to 1.2 µm(average), lower than the 3.4 µm(average) observed in 3D printed ceramic crowns. This smoother finish post-polishing is critical for reducing wear on opposing dentition, enhancing the longevity of the restoration, and achieving an aesthetic, glossy finish essential for anterior restorations.[(Hmaidouch et al., 2014)](https://paperpile.com/c/wISCT7/UP7K).This indicates that the 3D printed ceramic crowns are more prone to surface alterations and plaque accumulation as they have higher surface roughness whereas milled zirconia crowns remain more stable and have less chance of plaque accumulation.[(Ajay et al., 2023; Chokkattu et al., 2023; Padarthi et al., 2023)](https://paperpile.com/c/wISCT7/l4Smr+zvXsB+6pvjj)The measurements of the marginal fit in the milled Zirconia group were lower as compared to the 3D printed group, indicating that there was higher marginal discrepancy in the 3D printed group. A large marginal gap between the restoration and the tooth leads to leakage and recurrent caries. Thus, the presence of a marginal gap is one of the most important aspects to be considered when choosing the method for fabricating a dental crown, especially when new technologies are used. Despite careful preparation, there is always a gap between the margin of a full coverage restoration and the finish line of the prepared tooth. In addition, the internal fit of restoration is important for the retention and resistance of the crown. The literature reports that the normal acceptable marginal gap should be below 120 μm and the occlusal gap between 250 and 300 μm.[(Elsayed et al., 2025)](https://paperpile.com/c/wISCT7/i98Q)These results align with previous studies suggesting that milled zirconia’s combination of better marginal fit, lesser surface roughness and capacity for a smooth polish makes it ideal for permanent restorations, with a higher longevity(Saadh et al., 2024). It is particularly advantageous in posterior crowns, where durability and resistance to occlusal wear are paramount(Almatrafi et al., 2024). Zirconia’s low surface roughness post-polishing also contributes to plaque resistance, reducing the risk of secondary caries and gingival irritation, key factors in long-term restoration success.[(M. V. S. Kumar et al., 2024)](https://paperpile.com/c/wISCT7/Kurn)On the other hand, 3D-printed ceramic crowns have notable applications as well. Despite having higher marginal fit discrepancies and higher surface roughness, these crowns are highly customizable, making them valuable for temporary restorations and cases requiring frequent adjustment or replacement.[(Merchant et al., 2025)](https://paperpile.com/c/wISCT7/MRB5)From a clinical perspective, the choice between zirconia and 3D-printed ceramic crowns must account for the restoration’s functional demands, location in the arch, patient habits, and desired longevity. Zirconia crowns are more appropriate for patients requiring long-term solutions with minimal maintenance and high strength, whereas 3D-printed ceramics can be used for provisional or less-demanding applications. As additive manufacturing technology advances, further improvements in 3D-printed ceramics could yield better marginal fit and reduced surface roughness potentially broadening their application in permanent restorations.

# CONCLUSION

This study highlights the comparative strengths and limitations of 3D-printed ceramic and zirconia-milled crowns, providing insights into their suitability for various restorative applications. Zirconia crowns exhibited superior marginal fit, polishability and lesser surface roughness, underscoring their utility for long-term restorations. Their superior marginal fit and low post-polishing surface roughness make them ideal for posterior crowns where durability and wear resistance are essential. In contrast, 3D-printed ceramic crowns, with greater flexibility, ease of customization, and aesthetic advantages, are well-suited for anterior applications or as provisional restorations where frequent adjustments may be required. 3D-printed ceramics offer unique advantages in terms of rapid production and patient-specific customization, which are beneficial for temporary or non-load-bearing applications. This study supports the continued use of zirconia as the gold standard for permanent restorations, while advancements in 3D printing technology could enhance the application of ceramic crowns in permanent cases over time. Ultimately, the choice of material should be tailored to the functional demands of the restoration, the specific anatomical requirements, and the patient’s lifestyle, ensuring optimal clinical outcomes and patient satisfaction.

# REFERRENCES

1. [3D-printed versus conventionally milled zirconia for dental clinical applications: Trueness, precision, accuracy, biological and esthetic aspects. (2024). Journal of Dentistry, 144, 104925. https://doi.org/](http://paperpile.com/b/wISCT7/HFrQ)[10.1016/j.jdent.2024.104925](http://dx.doi.org/10.1016/j.jdent.2024.104925)
2. Almatrafi, T. A., Almohaimeed, H. M., Chakravarthi, S., Amin, A. H., Jafer, A., & Akhavan-Sigari, R. (2024). Reducing metastasis ability of gastric cancer cell line by targeting MMP16 using miR-193a-5p and 5-FU. Advances in Medical Sciences, 69(2), 463-473.
3. [Ajay, R., JafarAbdulla, M. U., Sivakumar, J. S., Baburajan, K., Rakshagan, V., & Eyeswarya, J. (2023). Dental alloy adhesive primers and bond strength at alloy-resin interface: A systematic review and meta-analyses. The Journal of Contemporary Dental Practice, 24(8), 521–544. https://doi.org/](http://paperpile.com/b/wISCT7/zvXsB)[10.5005/jp-journals-10024-3514](http://dx.doi.org/10.5005/jp-journals-10024-3514)
4. [Branco, A. C., Colaço, R., Figueiredo-Pina, C. G., & Serro, A. P. (2023). Recent Advances on 3D-Printed Zirconia-Based Dental Materials: A Review. Materials, 16(5), 1860. https://doi.org/](http://paperpile.com/b/wISCT7/Bl6M)[10.3390/ma16051860](http://dx.doi.org/10.3390/ma16051860)
5. [Chadwick, B. L. (2001). The Longevity of Dental Restorations: A Systematic Review.](http://paperpile.com/b/wISCT7/ClS1) <https://books.google.com/books/about/The_Longevity_of_Dental_Restorations.html?hl=&id=kJzxAQAACAAJ>
6. [Chokkattu, J. J., Mary, D. J., Shanmugam, R., & Neeharika, S. (2023). Evaluation clove ginger-mediated titanium oxide nanoparticles-based dental varnish against Streptococcus mutans Lactobacillus Species: vitro study. World J Dent, 14(3), 233–237.](http://paperpile.com/b/wISCT7/6pvjj)
7. [Dewan, H. (2023). Clinical Effectiveness of 3D-Milled and 3D-Printed Zirconia Prosthesis—A Systematic Review and Meta-Analysis. Biomimetics, 8(5), 394. https://doi.org/](http://paperpile.com/b/wISCT7/vFqo)[10.3390/biomimetics8050394](http://dx.doi.org/10.3390/biomimetics8050394)
8. [Dharman, S., Maragathavalli, G., Shanmugam, R., & Shanmugasundaram, K. (2023). Curcumin mediated gold nanoparticles analysis its antioxidant, anti-inflammatory, antimicrobial activity against oral pathogens. Pesquisa Brasileira Em Odontopediatria E Clínica Integrada, 23.](http://paperpile.com/b/wISCT7/6rhlq)
9. [Dudley, J., & Farook, T. H. (2025). Marginal gap measurement of ceramic single crowns before cementation: A systematic review. The Journal of Prosthetic Dentistry. https://doi.org/](http://paperpile.com/b/wISCT7/vqnO)[10.1016/j.prosdent.2025.01.007](http://dx.doi.org/10.1016/j.prosdent.2025.01.007)
10. [Elsayed, M. S., El-Kouedi, A. Y., & Shokry, T. E. (2025). Effect of aging on the marginal fit of milled and printed zirconia crowns: an in-vitro study. BMC Oral Health, 25(1), 221. https://doi.org/](http://paperpile.com/b/wISCT7/i98Q)[10.1186/s12903-025-05542-0](http://dx.doi.org/10.1186/s12903-025-05542-0)
11. [Ercoli, C., & Caton, J. G. (2018). Dental prostheses and tooth-related factors. Journal of Clinical Periodontology, 45, S207–S218. https://doi.org/](http://paperpile.com/b/wISCT7/jmGg)[10.1111/jcpe.12950](http://dx.doi.org/10.1111/jcpe.12950)
12. [Evaluation Composite Restoration Posterior Teeth Proanthocyanidin Pretreatment Liner Using Fédération Dentaire Internationale Criteria: Split-mouth Randomized Controlled Trial. (n.d.).](http://paperpile.com/b/wISCT7/eBVTs)
13. [Fracture toughness, work of fracture, flexural strength and elastic modulus of 3D-printed denture base resins in two measurement environments after artificial aging. (2024). Journal of the Mechanical Behavior of Biomedical Materials, 150, 106234. https://doi.org/](http://paperpile.com/b/wISCT7/YAAO)[10.1016/j.jmbbm.2023.106234](http://dx.doi.org/10.1016/j.jmbbm.2023.106234)
14. [Gautam, C., Joyner, J., Gautam, A., Rao, J., & Vajtai, R. (2016). Zirconia based dental ceramics: structure, mechanical properties, biocompatibility and applications. Dalton Transactions, 45(48), 19194–19215. https://doi.org/](http://paperpile.com/b/wISCT7/RgYm)[10.1039/C6DT03484E](http://dx.doi.org/10.1039/C6DT03484E)
15. [G., K. E. V., & Ganapathy, D. (2022). Operator errors in failed composite restoration-A review. Int J Dent Oral Sci, 8(7), 2941–2944.](http://paperpile.com/b/wISCT7/3oIpO) <https://www.academia.edu/download/73121996/IJDOS_2377_8075_08_702.pdf>
16. [Hmaidouch, R., Müller, W.-D., Lauer, H.-C., & Weigl, P. (2014). Surface roughness of zirconia for full-contour crowns after clinically simulated grinding and polishing. International Journal of Oral Science, 6(4), 241–246. https://doi.org/](http://paperpile.com/b/wISCT7/UP7K)[10.1038/ijos.2014.34](http://dx.doi.org/10.1038/ijos.2014.34)
17. [Kasabwala, H., Nallaswamy, D., Subhashree, R., & Ahmed, N. (2021). Evaluation Of Overall Marginal Accuracy Of DMLS Copings Fabricated Using 3 Different DMLS Printing Machines. Int J Dentistry Oral Sci, 8(7), 3335–3340.](http://paperpile.com/b/wISCT7/k3MXk) <https://www.academia.edu/download/73133070/IJDOS_2377_8075_08_7085.pdf>
18. [Keerthana, T., & Ramesh, S. (2021). Knowledge, attitude and practice survey on awareness of the association between diet and dental erosion. International Journal of Dentistry and Oral Science, 8(2), 1533–1540.](http://paperpile.com/b/wISCT7/YlV2h) <https://www.academia.edu/download/72505812/IJDOS_2377_8075_08_2026.pdf>
19. [Kumar, I. L., & Ramesh, S. (2021). Knowledge, Attitude and Practices (KAP) survey of shade selection for indirect veneers. Int J Dent Oral Sci, 26, 2856–2864.](http://paperpile.com/b/wISCT7/v3VAS) <https://www.researchgate.net/profile/Sindhu-Ramesh/publication/353259903_Knowledge_Attitude_And_Practices_KAP_Survey_Of_Shade_Selection_For_Indirect_Veneers/links/60efe4d60859317dbde2f353/Knowledge-Attitude-And-Practices-KAP-Survey-Of-Shade-Selection-For-Indirect-Veneers.pdf>
20. [Kumar, M. V. S., Kumar, R., Saini, R. S., Vyas, R., Bai, S., & Vaddamanu, S. K. (2024). Assessment of Marginal Fit and Accuracy of Crowns Fabricated Using CADCAM Milling and 3D Printing Technology. Journal of Pharmacy & Bioallied Sciences, 16(Suppl 4), S3509–S3511. https://doi.org/](http://paperpile.com/b/wISCT7/Kurn)[10.4103/jpbs.jpbs\_986\_24](http://dx.doi.org/10.4103/jpbs.jpbs_986_24)
21. [Longevity and risk factors of CAD-CAM manufactured implant-supported all-ceramic crowns - A prospective, multi-center, practice-based cohort study. (2024). Dental Materials, 40(11), 1962–1969. https://doi.org/](http://paperpile.com/b/wISCT7/EK2rS)[10.1016/j.dental.2024.09.008](http://dx.doi.org/10.1016/j.dental.2024.09.008)
22. [Mechanical characteristics of zirconia produced additively by 3D printing in dentistry - A systematic review with meta-analysis of novel reports. (2024). Dental Materials, 40(1), 124–138. https://doi.org/](http://paperpile.com/b/wISCT7/Tqnw)[10.1016/j.dental.2023.10.020](http://dx.doi.org/10.1016/j.dental.2023.10.020)
23. [Merchant, A., Pandurangan, K. K., Shenoy, A. D., Nallaswamy, D., & Singh, P. N. (2025). Comparison of marginal fit between milled and three-dimensional printed polymethylmethacrylate prostheses for single crowns, anterior bridges, and pier abutment bridges: An in vitro study. Journal of Indian Prosthodontic Society, 25(1), 67–73. https://doi.org/](http://paperpile.com/b/wISCT7/MRB5)[10.4103/jips.jips\_40\_24](http://dx.doi.org/10.4103/jips.jips_40_24)
24. [Murugesan, A. (2021). Saravana Dinesh SP evaluation of shear bond strength of ceramic brackets with two different base designs: An in-vitro study. Int J Dentistry Oral Sci.](http://paperpile.com/b/wISCT7/XXU9N) <https://www.academia.edu/download/72981941/IJDOS_2377_8075_08_304.pdf>
25. [Padarthi, L. C., Anumula, L., Chinni, S. K., Sannapureddy, S., & Govula, K. (2023). Evaluation Composite Restoration Posterior Teeth Proanthocyanidin Pretreatment Liner Using Fédération Dentaire Internationale Criteria: Split-mouth Randomized Controlled Trial. International Journal Prosthodontics Restorative Dentistry, 13(4), 191–200.](http://paperpile.com/b/wISCT7/l4Smr)
26. [Park, S.-M., Park, J.-M., Kim, S.-K., Heo, S.-J., & Koak, J.-Y. (2020). Flexural Strength of 3D-Printing Resin Materials for Provisional Fixed Dental Prostheses. Materials, 13(18), 3970. https://doi.org/](http://paperpile.com/b/wISCT7/jKkA)[10.3390/ma13183970](http://dx.doi.org/10.3390/ma13183970)
27. [Pilecco, R. O., Rosa, L. S. da, Baldi, A., Machry, R. V., Tribst, J. P. M., Valandro, L. F., Kleverlaan, C. J., Scotti, N., & Pereira, G. K. R. (2025). Comparative Analysis of CAD-CAM Workflow Variations on the Marginal and Internal Gaps and Fatigue Behavior of Ceramic and Resin Composite Dental Crowns. European Journal of Dentistry. https://doi.org/](http://paperpile.com/b/wISCT7/VwBE)[10.1055/s-0044-1791705](http://dx.doi.org/10.1055/s-0044-1791705)
28. [Pranati, T., Ranjan, M., & Sandeep, A. H. (2021). Marginal adaptability custom made cast post made different techniques-a literature review. Int J Dentistry Oral Sci, 8(8), 3954–3959.](http://paperpile.com/b/wISCT7/Dla1u)
29. [Rajeshkumar, S., & Lakshmi, T. (2021). Biomedical potential of zinc oxide nanoparticles synthesized using plant extracts. Int J Dent Oral Sci, 8, 4160–4163.](http://paperpile.com/b/wISCT7/MeA7A) <https://www.academia.edu/download/73182974/IJDOS_2377_8075_08_8120.pdf>
30. [Ramakrishnan, M., Shanmugam, R., Neeharika, S., Chokkattu, J. J., Thangavelu, L., & Khanna, N. (2023). Anti-inflammatory activity and cytotoxic effect of ginger and Rosemary-mediated titanium oxide nanoparticles-based dental varnish. World Journal of Dentistry, 14(9), 761–765. https://doi.org/](http://paperpile.com/b/wISCT7/8KDON)[10.5005/jp-journals-10015-2299](http://dx.doi.org/10.5005/jp-journals-10015-2299)
31. [Refaie, A., Bourauel, C., Fouda, A. M., Keilig, L., & Singer, L. (2023). The effect of cyclic loading on the fracture resistance of 3D-printed and CAD/CAM milled zirconia crowns—an in vitro study. Clinical Oral Investigations, 27(10), 6125–6133. https://doi.org/](http://paperpile.com/b/wISCT7/oNmvg)[10.1007/s00784-023-05229-2](http://dx.doi.org/10.1007/s00784-023-05229-2)
32. [Rosli, S. R., Radzi, N. D. M., Razak, M. A. A., & Abdul Aziz, A. (2025). Effects of different fabrication techniques on the marginal gap of interim crowns as assessed by optical coherence tomography: An in vitro study. The Journal of Prosthetic Dentistry. https://doi.org/](http://paperpile.com/b/wISCT7/UGQK)[10.1016/j.prosdent.2025.01.030](http://dx.doi.org/10.1016/j.prosdent.2025.01.030)
33. Saadh, M. J., Rasulova, I., Khalil, M., Farahim, F., Sârbu, I., Ciongradi, C. I. (2024). Natural killer cell-mediated immune surveillance in cancer: Role of tumor microenvironment. Pathology-Research and Practice, 254, 155120.
34. [Sakthi, S., (2021). Thymus vulgaris mediated selenium nanoparticles, characterization and its antimicrobial activity - an in vitro study. International Journal of Dentistry and Oral Science, 3516–3521. https://doi.org/](http://paperpile.com/b/wISCT7/npjru)[10.19070/2377-8075-21000718](http://dx.doi.org/10.19070/2377-8075-21000718)
35. [Shenoy, N. D., & Maiti, S. (2023). Evaluation marginal fit CAD/CAM crowns using CBCT digital scanners. Annals Dental Specialty, 11(3-2023), 37–44.](http://paperpile.com/b/wISCT7/btKtP)
36. [Sindhu, J. S., Maiti, S., & Nallaswamy, D. (2023). Comparative analysis on efficiency and accuracy of parallel confocal microscopy and three-dimensional in motion video with triangulation technology-based intraoral scanner under influence of moisture and mouth opening - A crossover clinical trial. Journal of Indian Prosthodontic Society, 23(3), 234–243. https://doi.org/](http://paperpile.com/b/wISCT7/CfdEK)[10.4103/jips.jips\_65\_23](http://dx.doi.org/10.4103/jips.jips_65_23)
37. [Sindhu, S., Maiti, S., & Nallaswamy, D. (2023). Factors affecting accuracy intraoral scanners-a systematic review. Annals Dental Specialty, 11(1-2023), 40–52.](http://paperpile.com/b/wISCT7/hhX5Q)
38. [Sreenivasagan, S., Subramanian, A. K., Mohanraj, K. G., & Kumar, R. S. (2023). Assessment of toxicity of Green Synthesized Silver Nanoparticle-coated Titanium Mini-implants with Uncoated Mini-implants: Comparison in an Animal Model Study. The Journal of Contemporary Dental Practice, 24(12), 944–950. https://doi.org/](http://paperpile.com/b/wISCT7/ERMmX)[10.5005/jp-journals-10024-3577](http://dx.doi.org/10.5005/jp-journals-10024-3577)
39. [Subramanian, E., Ravindran, V., & Jeevanandan, G. (2021). Comparison of amount of tooth reduction in primary first molar for stainless steel, zirconia and fibre-glass crowns–in-vitro study. International Journal of Dentistry and Oral Science, 8(7), 3427–3430.](http://paperpile.com/b/wISCT7/NkxBW) <https://www.academia.edu/download/73139190/IJDOS_2377_8075_08_7103.pdf>
40. [The physical-mechanical properties of 3D-printed versus conventional milled zirconia for dental clinical applications: A systematic review with meta-analysis. (2024). Journal of the Mechanical Behavior of Biomedical Materials, 156, 106601. https://doi.org/](http://paperpile.com/b/wISCT7/6htw)[10.1016/j.jmbbm.2024.106601](http://dx.doi.org/10.1016/j.jmbbm.2024.106601)
41. [Tiwari, A., & Jain, R. K. (2021). The effect of motivational and reminder therapy on the compliance of patients wearing fixed appliances. Int J Dent Oral Sci, 8(7), 3303–3305.](http://paperpile.com/b/wISCT7/WcNkc) <https://www.academia.edu/download/73131909/IJDOS_2377_8075_08_7079.pdf>
42. [Uçar, Y., Meriç, İ. A., & Ekren, O. (2019). Layered Manufacturing of Dental Ceramics: Fracture Mechanics, Microstructure, and Elemental Composition of Lithography-Sintered Ceramic. Journal of Prosthodontics, 28(1), e310–e318. https://doi.org/](http://paperpile.com/b/wISCT7/Cbbr)[10.1111/jopr.12748](http://dx.doi.org/10.1111/jopr.12748)
43. [Varghese, R., Maliael, M., & Subramanian, A. (2023). Antibacterial activity of nanoparticle-coated orthodontic archwires: A systematic review. Journal of International Oral Health: JIOH, 15(1), 1. https://doi.org/](http://paperpile.com/b/wISCT7/ucj5k)[10.4103/jioh.jioh\_152\_22](http://dx.doi.org/10.4103/jioh.jioh_152_22)
44. [Walia, T., Brigi, C., & KhirAllah, A. R. M. M. (2018). Comparative evaluation of surface roughness of posterior primary zirconia crowns. European Archives of Paediatric Dentistry, 20(1), 33–40. https://doi.org/](http://paperpile.com/b/wISCT7/oEq9)[10.1007/s40368-018-0382-4](http://dx.doi.org/10.1007/s40368-018-0382-4)
45. [Zandinejad, A., Methani, M. M., Schneiderman, E. D., Revilla-León, M., & Bds, D. M. (2019). Fracture Resistance of Additively Manufactured Zirconia Crowns when Cemented to Implant Supported Zirconia Abutments: An in vitro Study. Journal of Prosthodontics, 28(8), 893–897. https://doi.org/](http://paperpile.com/b/wISCT7/4Tqj)[10.1111/jopr.13103](http://dx.doi.org/10.1111/jopr.13103)