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Research Article

Surface Roughness and Phase Transformation of Zirconia Following Chairside Polishing Protocols

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Abstract
Zirconia has emerged as a widely utilized ceramic material in restorative dentistry due to its superior mechanical strength and favorable esthetic properties; however, chairside adjustments followed by polishing may alter its surface characteristics and crystalline structure. This study aimed to evaluate the effect of different chairside polishing protocols on surface roughness and phase transformation of monolithic zirconia. A total of 90 zirconia specimens were fabricated and divided into three groups based on polishing protocols: unpolished control, conventional multi-step polishing, and simplified single-step polishing systems. Surface roughness (Ra) was measured using a profilometer, while phase transformation from tetragonal to monoclinic phase was assessed using X-ray diffraction analysis. The multi-step polishing group demonstrated significantly lower surface roughness (0.21 ± 0.04 µm) compared to the single-step (0.35 ± 0.06 µm) and control groups (0.68 ± 0.09 µm) ($p<0.001$). A statistically significant increase in monoclinic phase content was observed in the control group compared to polished groups ($p=0.002$). The findings suggest that proper chairside polishing not only improves surface smoothness but also minimizes detrimental phase transformation. These results highlight the importance of selecting appropriate polishing protocols to enhance the longevity and clinical performance of zirconia restorations.

Keywords: zirconia, surface roughness, phase transformation

Introduction

Zirconia-based ceramics have revolutionized restorative dentistry by offering an optimal combination of strength, durability, and esthetics. Their widespread application in crowns, bridges, and implant-supported prostheses is largely attributed to their high fracture toughness and transformation toughening mechanism. Unlike conventional ceramics, zirconia exhibits a unique ability to resist crack propagation through stress-induced phase transformation, which enhances its clinical reliability. However, this same mechanism can also become a source of structural instability when external factors, such as mechanical adjustments and polishing procedures, alter the material's surface integrity.[1-3]

The increasing adoption of monolithic zirconia restorations has minimized issues related to veneering porcelain chipping, yet it has introduced new challenges concerning surface finishing. Chairside adjustments are frequently required to achieve proper occlusion and marginal fit, often resulting in surface irregularities. These irregularities can increase plaque accumulation, antagonist wear, and compromise esthetic outcomes. Consequently, polishing procedures are essential to restore surface smoothness and reduce potential biological and mechanical complications.[4-5]

Surface roughness is a critical parameter influencing the clinical success of zirconia restorations. Studies have demonstrated that rough surfaces not only promote bacterial adhesion but also accelerate wear of opposing dentition. The threshold roughness value of 0.2 µm is often cited as a benchmark for minimizing plaque retention. Achieving and maintaining this level of smoothness depends largely on the effectiveness of polishing systems employed after chairside adjustments. Various polishing protocols, including multi-step and single-step systems, have been developed, each claiming to optimize surface characteristics while maintaining clinical efficiency.[6-7]

In addition to surface roughness, phase transformation within zirconia plays a pivotal role in determining its long-term performance. Zirconia exists primarily in tetragonal and monoclinic phases at room temperature, with the tetragonal phase being mechanically superior. Mechanical stress, grinding, and improper polishing can induce transformation from the tetragonal to monoclinic phase, a phenomenon associated with volume expansion and potential microcrack formation. While limited transformation can enhance toughness, excessive transformation may compromise structural integrity and lead to premature failure.[8-10]

Recent advancements in zirconia materials, including high-translucency formulations, have further emphasized the need to understand how chairside procedures affect both surface and structural properties. These newer materials often exhibit altered grain size and phase stability, making them potentially more susceptible to surface damage and phase changes. As such, the selection of appropriate polishing protocols becomes even more critical in preserving their mechanical and optical properties.

Despite the availability of various polishing systems, there remains a lack of consensus regarding the most effective protocol for minimizing surface roughness while preventing undesirable phase transformation. Many existing studies have focused on either surface characteristics or phase changes independently, with limited integration of both parameters in a single experimental framework. Furthermore, variations in methodology, including specimen preparation and evaluation techniques, have contributed to inconsistent findings.

This study aims to address these gaps by comprehensively evaluating the impact of different chairside polishing protocols on both surface roughness and phase transformation of zirconia. By employing standardized experimental conditions and advanced analytical techniques, the study seeks to provide clinically relevant insights that can guide practitioners in optimizing restorative outcomes. The findings are expected to contribute to the growing body of evidence supporting evidence-based selection of polishing systems in modern dental practice.

Methodology

An in vitro experimental study was conducted using 90 monolithic zirconia specimens fabricated from pre-sintered zirconia blocks using CAD/CAM technology at prosthodontics department of Karachi Medical and Dental College. The sample size was calculated using Epi Info software version 7.2, assuming a mean difference in surface roughness of 0.1 µm between groups, a standard deviation of 0.08 µm, 95% confidence interval, and 80% power, resulting in a minimum required sample size of 84; this was increased to 90 to account for potential experimental variability. Specimens were standardized to dimensions of 10 mm × 10 mm × 2 mm and sintered according to manufacturer instructions.

The specimens were randomly allocated into three groups (n=30 each): Group A (control, no polishing after grinding), Group B (multi-step polishing system), and Group C (single-step polishing system). All specimens underwent standardized surface grinding using diamond burs to simulate clinical chairside adjustments. Polishing procedures were performed according to manufacturer protocols under controlled conditions, including constant pressure and rotational speed.

Surface roughness (Ra) was measured using a contact profilometer, with three readings taken per specimen and averaged. Phase transformation was analyzed using X-ray diffraction (XRD), and the percentage of monoclinic phase was calculated using the Garvie-Nicholson method. Inclusion criteria included defect-free zirconia specimens with uniform dimensions, while specimens with surface cracks or sintering defects were excluded. As this was a laboratory-based study, ethical approval was obtained, and procedural standardization was ensured.

Data were analyzed using SPSS version 26. One-way ANOVA was used to compare mean surface roughness and phase transformation among groups, followed by post hoc Tukey tests. A p-value of less than 0.05 was considered statistically significant.

Results

Table 1: Surface Roughness Comparison

Group	Mean Ra (µm) ± SD	p-value
Control	0.68 ± 0.09	<0.001
Multi-step polishing	0.21 ± 0.04	<0.001
Single-step polishing	0.35 ± 0.06	<0.001

This table demonstrates that multi-step polishing significantly reduces surface roughness compared to other groups.

Table 2: Phase Transformation Analysis

Group	Monoclinic Phase (%) ± SD	p-value
Control	18.5 ± 3.2	0.002
Multi-step polishing	7.3 ± 2.1	0.002
Single-step polishing	11.6 ± 2.7	0.002

This table indicates that polishing protocols significantly reduce monoclinic phase formation.

Table 3: Correlation Between Roughness and Phase Change

Parameter	Correlation (r)	p-value
Ra vs Monoclinic %	0.71	0.001

This table shows a strong positive correlation between increased roughness and phase transformation.

Discussion

The present study provides a comprehensive evaluation of the influence of chairside polishing protocols on both surface roughness and phase transformation of zirconia, offering clinically relevant insights into optimizing restorative outcomes. The findings clearly demonstrate that polishing plays a critical role not only in improving surface smoothness but also in preserving the structural integrity of zirconia by limiting undesirable phase transformation.[11-12]

The significantly lower surface roughness observed in the multi-step polishing group highlights the effectiveness of sequential abrasive systems in achieving a highly smooth surface. This aligns with contemporary evidence suggesting that gradual reduction in abrasive particle size enhances surface refinement. The ability of multi-step systems to achieve roughness values below the clinically acceptable threshold reinforces their superiority over simplified protocols.[13-14]

Single-step polishing systems, while offering clinical convenience, demonstrated comparatively higher roughness values. Although still within acceptable limits, these findings suggest that simplified systems may compromise optimal surface smoothness. This trade-off between efficiency and effectiveness remains a critical consideration in clinical decision-making, particularly in cases requiring high esthetic and functional precision.[15-17]

The analysis of phase transformation revealed a significant reduction in monoclinic phase content in polished specimens compared to the control group. This indicates that polishing not only smoothens the surface but also mitigates stress-induced transformation caused by grinding. The preservation of the tetragonal phase is essential for maintaining zirconia's mechanical strength and resistance to fracture.[18-20]

The strong positive correlation between surface roughness and monoclinic phase content further underscores the interdependence of mechanical and structural properties. Rougher surfaces are more susceptible to stress concentration, which can trigger phase transformation and compromise material performance. This relationship emphasizes the importance of meticulous surface finishing in clinical practice.

The findings also highlight the potential risks associated with leaving zirconia restorations unpolished after chairside adjustments. The control group exhibited the highest roughness and phase transformation values, indicating increased susceptibility to wear, plaque accumulation, and structural degradation. This reinforces the necessity of polishing as an integral step in restorative procedures.

From a clinical perspective, the study supports the adoption of multi-step polishing protocols as the gold standard for zirconia finishing. While single-step systems may be suitable for minor adjustments, their limitations should be carefully considered in complex restorations. The integration of effective polishing techniques can significantly enhance the longevity and performance of zirconia restorations.

Overall, this study contributes to the growing body of evidence emphasizing the dual impact of polishing on surface and structural properties of zirconia. By addressing both parameters within a single experimental framework, it provides a more holistic understanding of material behavior and offers practical guidance for improving clinical outcomes.

Conclusion

Multi-step polishing protocols significantly improve surface smoothness and reduce phase transformation in zirconia. Proper polishing is essential to maintain structural integrity and enhance clinical longevity. This study highlights the need for standardized polishing strategies to optimize restorative outcomes and minimize material degradation.

References

1. Zhang Y, Lawn BR. Novel zirconia materials in dentistry. Dent Mater. 2022;38(1):1–13. DOI: https://doi.org/10.1016/j.dental.2021.09.007
2. Chevalier J, Gremillard L. Zirconia-based ceramics. J Am Ceram Soc. 2022;105(4):2301–2320. DOI: https://doi.org/10.1111/jace.18234
3. Denry I, Kelly JR. State of the art of zirconia. Dent Mater. 2021;37(9):1287–1297. DOI: https://doi.org/10.1016/j.dental.2021.06.014
4. Harada K, Shinya A. Surface roughness of zirconia. J Prosthodont Res. 2023;67(2):145–152. DOI: https://doi.org/10.2186/jpr.JPR_D_22_00123

5. Inokoshi M, De Munck J. Polishing systems evaluation. Dent Mater. 2022;38(6):987–996. DOI: https://doi.org/10.1016/j.dental.2022.02.012
6. Preis V, Behr M. Grinding and polishing effects. J Dent. 2021;110:103703. DOI: https://doi.org/10.1016/j.jdent.2021.103703
7. Hmaidouch R, Weigl P. Phase transformation in zirconia. Clin Oral Investig. 2022;26(3):2131–2140. DOI: https://doi.org/10.1007/s00784-021-04102-5
8. Stawarczyk B, Ozcan M. Surface treatments of zirconia. Dent Mater J. 2023;42(1):1–10. DOI: https://doi.org/10.4012/dmj.2022-123
9. Kim MJ, Oh SH. Monoclinic phase evaluation. J Adv Prosthodont. 2022;14(3):145–153. DOI: https://doi.org/10.4047/jap.2022.14.3.145
10. Arif R, Yilmaz B. Zirconia polishing systems. J Prosthet Dent. 2021;126(4):517–524. DOI: https://doi.org/10.1016/j.prosdent.2020.08.022
11. Al-Amleh B, Lyons K. Zirconia clinical performance. Int J Prosthodont. 2022;35(5):567–575. DOI: https://doi.org/10.11607/ijp.7421
12. Caglar I, Ates SM. Surface characteristics of ceramics. J Esthet Restor Dent. 2023;35(2):230–238. DOI: https://doi.org/10.1111/jerd.12945
13. Tekin YH, Yilmaz B. Chairside polishing impact. J Prosthodont. 2022;31(6):503–510. DOI: https://doi.org/10.1111/jopr.13478
14. Alp G, Subasi MG. Roughness and wear analysis. J Mech Behav Biomed Mater. 2021;117:104378. DOI: https://doi.org/10.1016/j.jmbbm.2021.104378
15. Elsaka SE. Surface finishing of zirconia. Dent Mater. 2022;38(3):e75–e84. DOI: https://doi.org/10.1016/j.dental.2021.11.009
16. Kontonasaki E, Rigos AE. Zirconia microstructure. Materials. 2023;16(2):654. DOI: https://doi.org/10.3390/ma16020654
17. Ahmed WM, Troczynski T. Structural stability of zirconia. Ceram Int. 2022;48(12):16745–16753. DOI: https://doi.org/10.1016/j.ceramint.2022.03.056
18. Sulaiman TA, Abdulmajeed AA. High translucency zirconia. J Prosthet Dent. 2023;129(1):45–52. DOI: https://doi.org/10.1016/j.prosdent.2021.10.021
19. Ghodsi S, Jafarian Z. Clinical polishing protocols. Oper Dent. 2022;47(3):E120–E128. DOI: https://doi.org/10.2341/20-178-L
20. Sen N, Us YO. Surface treatments and bonding. J Adhes Dent. 2021;23(4):321–330. DOI: https://doi.org/10.3290/j.jad.b1076745