International Journal Dental and Medical Sciences Research
Volume 7, Issue 5, Sept – Oct 2025 pp 92-99 www.ijdmsrjournal.com ISSN: 2582-6018

# An In-Vitro Evaluation of the Effect of Artificial Aging on Surface Roughness of Three Brands of Zirconia

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Date of Submission: 05-09-2025 Date of Acceptance: 15-09-2025

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**ABSTRACT**
**Background:** Zirconia ceramics are widely used in fixed prosthodontics due to their superior strength, aesthetics, and biocompatibility. However, they are susceptible to low temperature degradation (LTD), a process that occurs under humid conditions and leads to tetragonal-to-monoclinic phase transformation, surface roughening, and compromised clinical performance. Evaluation of the long-term stability of different zirconia brands under artificial aging is therefore essential.
**Aim:** To evaluate and compare the effect of artificial aging on the surface roughness of three commercially available monolithic zirconia brands.
**Materials and Methods:** Forty-five monolithic zirconia crowns were fabricated using standardized tooth preparation on a maxillary first premolar typodont. A resin diewas 3D printed, and zirconia crowns were milled from three brands: Group A (Dentsply), Group B (Ivoclar), andGroup C (Upcera) (n=15 each)via CAD/CAM workflow. All crowns were sintered and glazed according to manufacturer's instructions. Artificial aging was carried out using an autoclave (134 °C, 2 bar, 5 hours) to simulate low temperature degradation (LTD). Surface roughness was measured before and after aging using a contact profilometer (Mitutoyo SJ-210). Data was statistically analysed using paired t-tests, one-way ANOVA, and post-hoc Tukey test ($\alpha = 0.05$).
**Results:** Artificial aging significantly increased surface roughness in all zirconia brands. Group C (Upcera) showed the highest mean post-aging Ra value (0.55 ± 0.09 µm), significantly higher than Group A (Dentsply) (0.48 ± 0.08 µm, $p = 0.031$) and Group C (Ivoclar) (0.44 ± 0.07 µm, $p = 0.009$). Differences between Group A (Dentsply) and Group B (Ivoclar) were not statistically significant ($p = 0.524$).
**Conclusion:** Artificial aging increased the surface roughness of zirconia crowns, with Upcera showing greater roughening compared to Group B (Dentsply) andGroup B (Ivoclar). These results indicate that zirconia brand and processing protocols influence long-term surface stability.
**Keywords :** Zirconia; Artificial aging; Surface roughness; CAD/CAM; Low temperature degradation (LTD).

## I. INTRODUCTION

Zirconia has become a cornerstone material in fixed prosthodontics owing to its superior strength, fracture toughness, biocompatibility, and esthetic potential compared with traditional ceramics and metal-ceramic restorations [1]. Over the last two decades, advances in powder processing and CAD/CAM technologies have enabled the widespread use of monolithic zirconia restorations, eliminating the need for veneering porcelain and thereby reducing the risk of chipping [2].

The most clinically utilized form of zirconia is yttria-stabilized zirconia (YSZ), which exists in different variants based on the concentration of stabilizers and processing protocols. The addition of yttria maintains the tetragonal phase at room temperature, imparting transformation toughening and superior mechanical performance [2]. However, despite these favorable properties, zirconia is not free from limitations. One of the most critical concerns is low temperature degradation (LTD), also termed "aging," which occurs in humid environments at temperatures between 65 °C and 400 °C [3]. During LTD, the metastable tetragonal phase progressively transforms into the monoclinic phase, a process accompanied by a 3–4% volume expansion, microcrack formation, and grain pull-out [4]. These microstructural changes deteriorate the mechanical strength, optical properties, and surface quality of zirconia, potentially compromising its long-term clinical success.

Surface roughness is a clinically relevant parameter because it directly influences biofilm accumulation, gingival inflammation, staining susceptibility, and wear of opposing dentition [5]. A smoother restoration surface is essential to minimize plaque retention and ensure patient comfort. However, the phase transformation associated with LTD increases surface irregularities, thereby elevating roughness and creating a less favourable oral environment.

To assess the long-term stability of zirconia, artificial aging techniques have been developed to simulate clinical degradation. Among these, autoclave-induced LTD (steam at 134 °C and 2 bar) is widely accepted as a reliable in-vitro method to accelerate the aging process within a clinically relevant time frame [6]. This allows researchers to evaluate the relative resistance of different zirconia brands and formulations to phase transformation and surface deterioration.

Given the increasing availability of zirconia materials from different manufacturers, variations in powder purity, yttria content, grain size, and sintering protocols may influence their susceptibility to LTD and subsequent surface roughening. Therefore, the present study was designed to evaluate and compare the effect of artificial aging on the surface roughness of three commercially available zirconia brands.

## II. MATERIALS & METHODS

**2.1 Sample Size and Grouping :** A total of 45 monolithic zirconia crowns were fabricated and divided into three groups which include 15 zirconia crowns in each group:

- Group A – 15 zirconia crowns fabricated using Dentsply monolith zirconia disk (12mm A1 shade)
- Group B – 15 zirconia crowns fabricated using Ivoclar monolith zirconia disk (14mm A1 shade)
- Group C – 15 zirconia crowns fabricated using Upcera monolith zirconia disk (12mm A1 shade)

**2.2 Sample preparation:**

A maxillary first premolar typodont tooth (Dentmark) was prepared using a high-speed handpiece (Being Foshan Airotor) .Occlusal reduction was performed using a flat-end tapered diamond bur (ISO 173/018, TF13 Mani), reducing non-functional cusps by 2 mm and functional cusps by 2.5 mm while maintaining anatomy. The same bur was used for axial reduction with depth orientation grooves, achieving a 6° convergence angle. A 1.5 mm wide shoulder finish line was then prepared, followed by refinement and polishing of all surfaces with fine and extra-fine finishing burs (ISO 198/018, TR13 Mani) to ensure smooth margins and rounded internal line angles

The prepared tooth was scanned (Primescan, Dentsply Sirona), and a resin die was 3D-printed. Zirconia crowns were designed in Exocad DentalCAD with an 80 µm cement space (except at the margins) and milled from three different zirconia discs: Group A – Dentsply, Group B – Ivoclar, and Group C – Upcera (n = 15 each). Milled crowns were sintered at 1450 °C as per manufacturer's instructions and glazed using their respective proprietary glaze pastes.Artificial aging was carried out in an autoclave at 134 °C, 2 bar for 5 hours.

**2.3 Surface roughness measurement :**

Surface roughness (Ra) was measured using a contact profilometer (Mitutoyo SJ-210). Three linear measurements were taken at different points on each specimen, and the mean value was considered. Measurements were recorded both before and after aging.[FIGURES 9&10].

**2.4 Statistical Analysis:**

Paired t-test (intra-group), one-way ANOVA, and post-hoc Tukey test (inter-group) were used. A p-value $< 0.05$ was considered statistically significant.

## III. RESULTS

Table 1 shows the intra-group comparison of mean surface roughness (Ra, µm) values before and after artificial aging. A consistent and statistically significant increase in Ra was observed in all three groups ($p < 0.05$). Group A demonstrated an increase from 0.32 ± 0.06 µm at baseline to 0.48 ± 0.08 µm after aging ($p = 0.004$). Group B showed a similar trend, rising from 0.30 ± 0.05 µm to 0.44 ± 0.07 µm ($p = 0.006$). Group C recorded the highest increase, from 0.34 ± 0.07 µm to 0.55 ± 0.09 µm ($p < 0.001$). These results clearly indicate that artificial aging induces surface roughening in all zirconia crowns, with Group C being the most affected.

Table 2 presents the inter-group comparison of post-aging values. The one-way ANOVA revealed a significant overall difference among the groups ($F = 6.42$, $p = 0.004$). Tukey's post-hoc test confirmed that Group C had significantly higher Ra values compared with Group A (+0.07 µm, $p = 0.031$) and Group B (+0.11 µm, $p = 0.009$). However, no significant difference was found between Group A and Group B (+0.04 µm, $p = 0.524$). This suggests that while Groups A and B behaved comparably, Group C exhibited a distinctly greater loss of surface integrity after aging.

From a clinical perspective, all groups crossed the roughness threshold of ~0.2 µm, a level reported in the literature as critical for increased plaque retention and wear of opposing dentition. The relatively higher post-aging roughness of Group C indicates a greater potential for plaque accumulation, discoloration, and antagonistic enamel wear compared to Groups A and B. Thus, although aging negatively affected all zirconia types, Group C appears more susceptible to clinically relevant surface deterioration.

## IV. DISCUSSION

This study demonstrated that artificial aging significantly increased the surface roughness of zirconia crowns across all three brands tested. These findings are in agreement with earlier reports that linked low temperature degradation (LTD) to progressive surface deterioration of zirconia [7,8]. The underlying mechanism involves the transformation of the metastable tetragonal phase to the monoclinic phase when exposed to humid and thermal conditions. This phase change is accompanied by a localized volume expansion, which induces surface stresses, microcracks, and eventual grain pull-out [9]. Over time, these microscopic defects accumulate, giving rise to a rougher and less uniform surface.

The differences noted among the three zirconia groups may be explained by variations in their microstructural and compositional characteristics. Grain size, the amount and distribution of yttria stabilizer, incorporation of colouring oxides, and differences in sintering protocols all influence the material's resistance to LTD [10]. Smaller and more homogeneously distributed grains generally provide greater resistance to phase transformation, whereas larger grains and certain colouring agents may accelerate the process. In this context, the higher Ra values observed in Group C suggest that its microstructure may be more vulnerable to transformation compared to Group A and Group B .

From a clinical standpoint, these findings are highly relevant. Literature indicates that surface roughness values above ~0.2 µm can lead to greater plaque accumulation, increased bacterial colonization, and higher susceptibility to staining [11]. Furthermore, rougher zirconia surfaces have been shown to accelerate the wear of opposing enamel, raising concerns regarding long-term functional outcomes. Since all three groups exceeded this threshold after aging, some degree of biological and mechanical compromise may be expected clinically. However, the markedly higher values in Group C may place restorations fabricated from this material at greater risk of plaque-related complications and antagonist wear in the long term.

The similarity between Group A and Group B suggests that both brands offer a relatively higher resistance to LTD-induced surface changes. For clinicians, this could translate into more predictable performance over time, particularly in patients with high functional demands or in situations where long-term plaque control is critical. Nonetheless, it is important to recognize that in-vitro aging cannot fully replicate the complex oral environment. Factors such as fluctuating pH, masticatory forces, thermal cycling, and salivary proteins may interact with LTD in ways not captured by the present protocol.

Overall, the results reinforce the importance of careful material selection in restorative dentistry. While all zirconia crowns were affected by aging, inter-brand differences highlight that not all monolithic zirconia behave identically, and their long-term performance may vary substantially.

## V. CONCLUSION

This study confirmed that artificial aging leads to a significant increase in surface roughness across all zirconia crowns tested. Group C (Upcera) showed the greatest susceptibility to roughening, whereas Group A (Dentsply) and Group B (Ivoclar) demonstrated lower and comparable post-aging values. Since all groups exceeded the clinically relevant threshold of ~0.2 µm, these changes may influence plaque retention, staining, and wear of opposing dentition. The results emphasize that not all zirconia brands perform equally under aging conditions, and long-term clinical success depends not only on strength and esthetics but also on the material's resistance to degradation.

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## FIGURE

**FIGURE 1: Tooth preparation done IRT 14**

**FIGURE 2: Virtual model obtained after scanning**

**International Journal Dental and Medical Sciences Research**
**Volume 7, Issue 5, Sept – Oct 2025 pp 92-99 www.ijdmsrjournal.com ISSN: 2582-6018**

**FIGURE 3: 3D printed resin die**

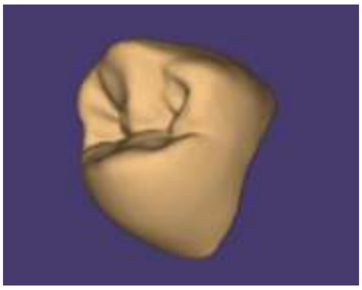

**FIGURE 4: Designed Crown**

**FIGURE5: Crowns milled through respective discs**

**FIGURE6: After Sintering**

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**FIGURE7: Application of glaze**

**FIGURE 8: Contact profilometer (Mitutoyo SJ-210).**

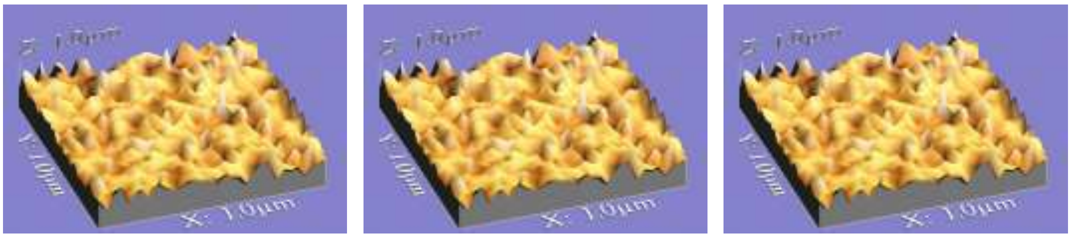

**FIGURE9:3D image showing surface topographic Features of Group A, Group B, Group C before artificial aging.**

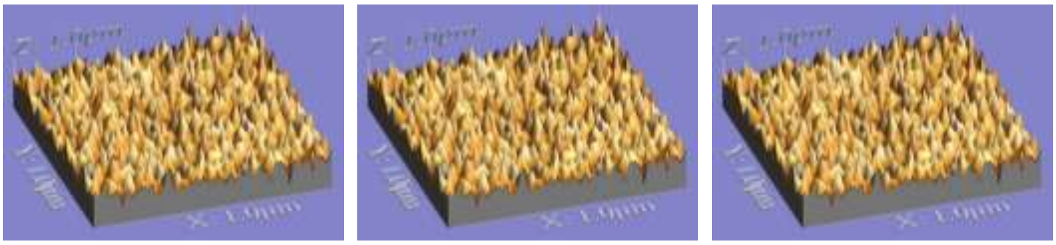

**FIGURE 10: 3D image showing surface topographic Features of Group A, Group B,Group C after artificial aging.**

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**DESCRIPTIVES**

TABLE 1

Mean surface roughness (Ra, µm) values of zirconia crowns before and after artificial aging

| Groups | N | Pre-aging Ra (Mean ± SD) | Post-aging Ra (Mean ± SD) | P-value |
|---|---|---|---|---|
| Group A | 15 | 0.32 ± 0.06 | 0.48 ± 0.08 | 0.004* |
| Group B | 15 | 0.30 ± 0.05 | 0.44 ± 0.07 | 0.006* |
| Group C | 15 | 0.34 ± 0.07 | 0.55 ± 0.09 | <0.001* |

*Statistically significant (P< 0.05).

Table 1 shows the intra-group comparison of mean surface roughness (Ra, µm) values before and after artificial aging.

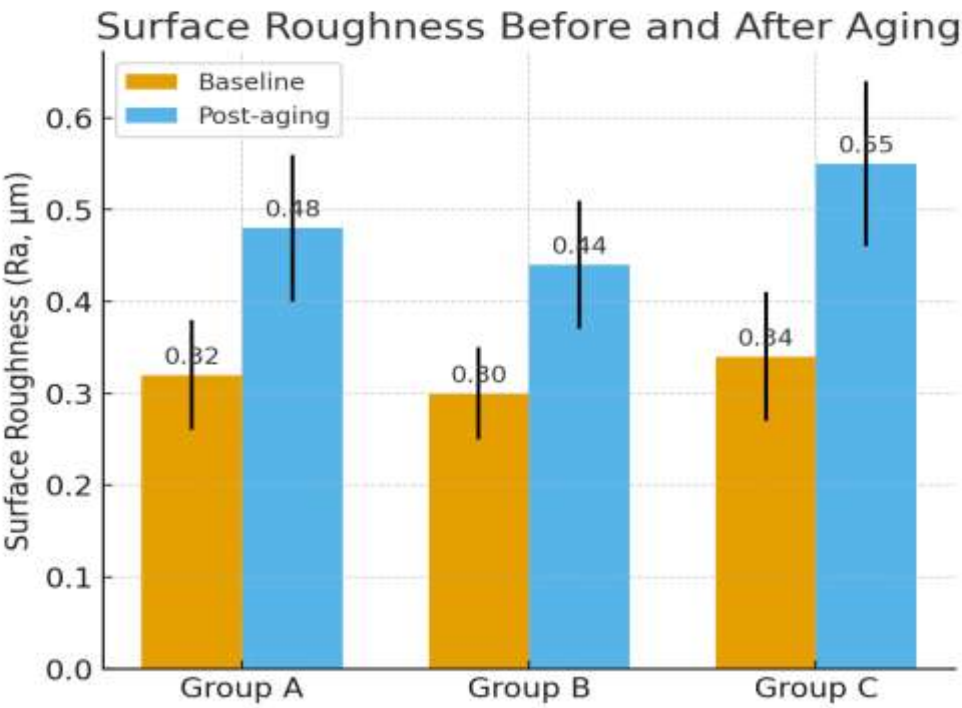
TABLE 2

Inter-group comparison of post-aging surface roughness (ANOVA and Tukey's post-hoc test)

| Comparison | Mean Difference (µm) | P-value | Significance |
|---|---|---|---|
| **Group C vs Group A** | +0.07 | 0.031 | Significant |
| **Group C vs Group B** | +0.11 | 0.009 | Significant |
| **Group A vs Group B** | +0.04 | 0.524 | NS |

ANOVA (post-aging values): F = 6.42, P = 0.004
NS = Not significant.
Tukey's post-hoc test : Group C>Group A (p = 0.031);Group C > Group B(p = 0.009); Group A vs Group C (NS, p = 0.524).
NS = Not significant.
Table 2 presents the inter-group comparison of post-aging values.

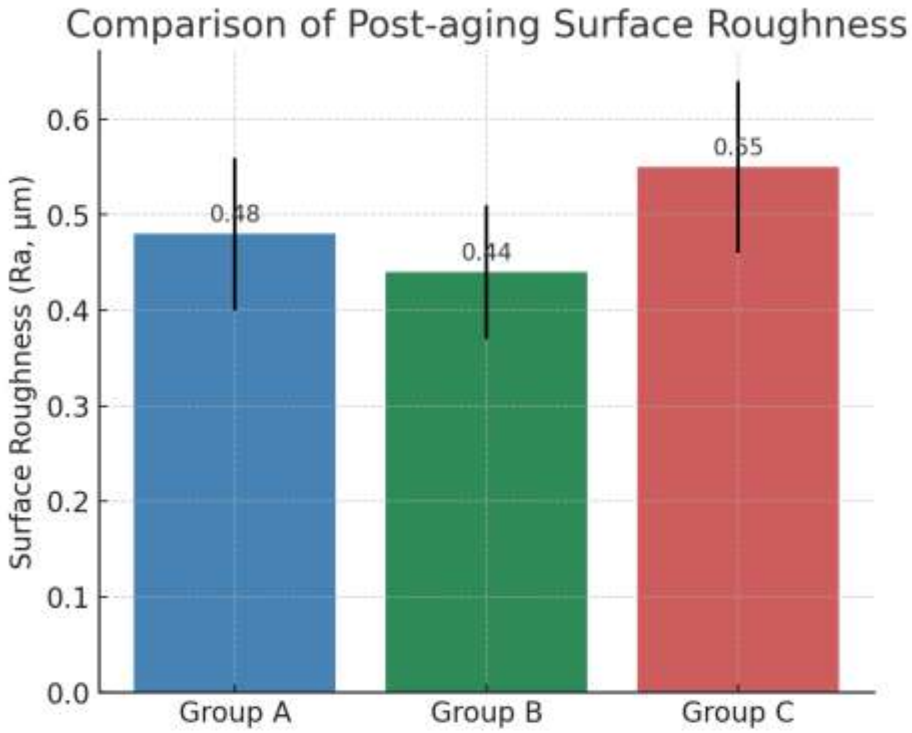
BAR DIAGRAM 1




Bar diagram 1 represents theBar graph showing baseline vs post-aging surface roughness (Ra) for each zirconia brand.

International Journal Dental and Medical Sciences Research
Volume 7, Issue 5, Sept – Oct 2025 pp 92-99 www.ijdmsrjournal.com ISSN: 2582-6018

BAR DIAGRAM 2




Bar diagram 2 represents the Bar graph showing Post-aging roughness among brands, highlighting that Group C is the roughest.