

## Marginal Discrepancy in Two CAD/CAM Zirconia Systems Subjected to Thermo Mechanical Cycling: A Stereomicroscopic Study

Abdelrazek M. Fayed<sup>1</sup>, Abdelrahman Essam Abdelrahman Elamassy<sup>2</sup>, Ahmed Mohammed Saleem Abdelglel<sup>3</sup>, Mostafa M. Ahmed<sup>4</sup>, Ahmed Y. Allam<sup>5</sup>, Ahmed Elsayed Elwan<sup>6</sup>, Suad M. Hassan<sup>7</sup>, Ashraf Marawan El Azzazy<sup>8</sup>.

<sup>1</sup> Lecturer of fixed prosthodontics, Faculty of Dental Medicine Al-Azhar University, Assiut Branch, Egypt.

E-mail: [abumalek.fayed@gmail.com](mailto:abumalek.fayed@gmail.com)

<sup>2</sup> BDS, MSc Prosthodontics Specialist, Andalusia Health, Jeddah, Saudi Arabia.

E-mail: [a.alrahman.essam@gmail.com](mailto:a.alrahman.essam@gmail.com)

<sup>3</sup> Lecturer of fixed prosthodontics, Faculty of Dental Medicine Al-Azhar University, Assiut Branch, Egypt.

E-mail: [ahmedsleem721@gmail.com](mailto:ahmedsleem721@gmail.com)

<sup>4</sup> Lecturer of fixed prosthodontics, Faculty of Dental Medicine Al-Azhar University, Assiut Branch, Egypt.

E-mail: [mostafa.abdeen1512@gmail.com](mailto:mostafa.abdeen1512@gmail.com)

<sup>5</sup> Lecturer of fixed prosthodontics, Faculty of Dental Medicine Al-Azhar University, Assiut Branch, Egypt.

E-mail: [ahmedallamyhln@gmail.com](mailto:ahmedallamyhln@gmail.com)

<sup>6</sup> Lecturer of fixed prosthodontics, Faculty of Dental Medicine (Boys), Al-Azhar University, Cairo, Egypt.

E-mail: [Ahmedelwan.209@azhar.edu.eg](mailto:Ahmedelwan.209@azhar.edu.eg)

<sup>7</sup> Assistant Professor, Department of Crowns and Bridges, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt. E-mail: [dr.suadmohamed@gmail.com](mailto:dr.suadmohamed@gmail.com).

<sup>8</sup> Lecturer, Department of Dental Biomaterial, Faculty of Dental Medicine, Assiut, AL Azhar University.

E-mail: [drashrafmarawan@gmail.com](mailto:drashrafmarawan@gmail.com)

### ABSTRACT

**Background:** Marginal adaptation constitutes a primary factor affecting the clinical longevity of all-ceramic fixed restorations. Despite the widespread clinical adoption of yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), concerns persist regarding its susceptibility to hydrothermal low-temperature degradation (LTD). Ceria-stabilized tetragonal zirconia/alumina nanocomposite (Ce-TZP/Al<sub>2</sub>O<sub>3</sub>; NANOZR) has been introduced as an alternative with potentially superior aging resistance.

**Objectives:** The purpose of the current research was to compare the marginal gap of NANOZR and Y-TZP all-ceramic crowns fabricated via CAD/CAM, prior to and following simulated thermo-mechanical aging.

**Materials and Methods:** Twenty-four full-coverage ceramic crowns were constructed on standardized epoxy-resin dies reproducing a mandibular first molar preparation (1.2 mm chamfer finish line; 1.5–2.0 mm occlusal reduction; 20° total occlusal convergence). Specimens were equally allocated to two groups (n = 12 each): Group I – NANOZR (Ce-TZP/Al<sub>2</sub>O<sub>3</sub>; Yamakin, Japan) and Group II – Y-TZP (Katana™; Kuraray Noritake, Japan). Each group was subdivided into aged (n = 6) and unaged (n = 6) subgroups. Thermo-mechanical aging was performed using a ROBOTA chewing simulator (150,000 cycles; 50 N; integrated thermocycling). Marginal gap measurements (20 points/crown) were obtained by stereomicroscopy at 45× and quantified using ImageJ software.

**Results:** Prior to aging, no significant inter-group difference was detected (p = 0.281). Following aging, Y-TZP demonstrated significantly greater marginal discrepancy than NANOZR (p = 0.035). Irrespective of material, thermo-mechanical aging significantly elevated overall marginal gap values (p < 0.0001). All recorded values remained below the

120 µm clinically acceptable threshold.

Conclusions: NANOZR exhibited superior marginal stability relative to Y-TZP following simulated oral aging, likely attributable to its nanocomposite alumina-reinforced microstructure conferring resistance to LTD. Both materials produced clinically acceptable marginal gaps under the conditions tested. Thermo-mechanical aging adversely affected marginal adaptation in both ceramic systems.

**Keywords:** Zirconia; Dental Marginal Adaptation; Computer-Aided Design; Dental Ceramics; Materials Testing.

**How to Cite:** Abdelrazek M. Fayed, Abdelrahman Essam Abdelrahman Elamassy, Ahmed Mohammed Saleem Abdelglel, Mostafa M. Ahmed, Ahmed Y. Allam, Ahmed Elsayed Elwan, Suad M. Hassan, Ashraf Marawan El Azzazy, (2024) Marginal Discrepancy in Two CAD/CAM Zirconia Systems Subjected to Thermo Mechanical Cycling: A Stereomicroscopic Study, *Journal of Carcinogenesis*, Vol.23, No.1, 1114-1122

## 1. INTRODUCTION

Contemporary prosthetic dentistry has witnessed a progressive shift toward metal-free restorative solutions, driven largely by evolving patient aesthetic expectations and advances in ceramic materials science. All-ceramic restorations offer distinct advantages over metal-ceramic systems, including superior optical translucency, enhanced biocompatibility, and improved simulation of natural dental tissue appearance [1,2].

Among the available all-ceramic frameworks, zirconia-based ceramics have acquired a prominent clinical status owing to their exceptional mechanical characteristics. The material has been described as ‘ceramic steel’ in the prosthodontic literature [3], reflecting a combination of flexural strength, fracture toughness, and fatigue resistance that is unparalleled among dental ceramics [4,5]. Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is most extensively employed for the fabrication of single-unit crowns and multi-unit fixed dental prostheses, supported by a favorable profile of chemical stability, dimensional accuracy, and Young’s modulus [6,7].

Nevertheless, two clinically relevant limitations have been identified for Y-TZP. The first concerns the risk of veneer porcelain chipping, particularly in posterior regions subject to masticatory loading. The second, and more material-intrinsic concern, involves low-temperature degradation (LTD), a hydrothermal aging phenomenon in which tetragonal-to-monoclinic phase transformation occurs in aqueous environments at body temperature, leading to surface micro-cracking and potential loss of mechanical integrity [8–10].

To address these limitations, a novel ceramic composition — ceria-stabilized tetragonal zirconia polycrystals reinforced with alumina nanoparticles (Ce-TZP/Al<sub>2</sub>O<sub>3</sub>, commercially designated as NANOZR) — was developed. In this nanocomposite system, Al<sub>2</sub>O<sub>3</sub> particles (10–100 nm) are intercalated within the ZrO<sub>2</sub> grain matrix and, conversely, nano-sized ZrO<sub>2</sub> particles are entrapped within the Al<sub>2</sub>O<sub>3</sub> grains, creating an intergranular interpenetrating network [11,12]. This unique nanoarchitecture has been reported to confer markedly greater resistance to hydrothermal aging compared with conventional Y-TZP, alongside superior biaxial flexural strength [12,13].

Marginal adaptation is universally recognized as a fundamental criterion for the clinical acceptability and longevity of fixed ceramic restorations. Inadequate marginal sealing predisposes restorations to marginal leakage, luting cement dissolution, plaque biofilm accumulation, and initiation of secondary caries, ultimately compromising both the restoration and the supporting periodontium [14,15]. In vitro simulation of the oral environment through thermocycling and mechanical loading provides a validated approach to accelerating the aging-related degradation to which restorations are subjected clinically [16].

Although previous investigations have examined the marginal adaptation of both Y-TZP and NANOZR ceramic systems, comparative data on the specific influence of combined thermo-mechanical aging on marginal discrepancy remain limited. The current research was therefore designed to evaluate and compare the marginal gap of NANOZR (Ce-TZP/Al<sub>2</sub>O<sub>3</sub>) and Y-TZP all-ceramic crowns fabricated using computer-aided design/computer-aided manufacturing (CAD/CAM) technology, both before and after simulated thermo-mechanical aging.

**The null hypothesis was that** no statistically significant difference in marginal adaptation would be observed between the two zirconia ceramic systems, either before or after thermo-mechanical aging.

## 2. MATERIALS AND METHODS

### 2.1 Study Materials

Two commercially available zirconia-based ceramic materials were evaluated: NANOZR (Ce-TZP/Al<sub>2</sub>O<sub>3</sub>; Yamakin Co., Ltd., Osaka, Japan) and Katana™ zirconia (Y-TZP; Kuraray Noritake Dental Inc., Tokyo, Japan). The compositional and physical specifications of each material are summarized in **Table 1**.

**Table 1: Compositional and physical specifications of the ceramic materials evaluated**

Material	Commercial Name	Manufacturer	Composition (wt%)	Particle Size
NANOZR	NANOZR	Yamakin Co., Ltd., Japan	ZrO <sub>2</sub> 67.9%, CeO <sub>2</sub> 10.6%, Al <sub>2</sub> O <sub>3</sub> 21.5%, HfO <sub>2</sub> <4%	0.49 μm; Al <sub>2</sub> O <sub>3</sub> 10–100 nm; ZrO <sub>2</sub> 10 nm
Y-TZP	Katana™	Kuraray Noritake, Japan	ZrO <sub>2</sub> 92.6%, Y <sub>2</sub> O <sub>3</sub> 5.3%, HfO <sub>2</sub> 1.78%, Al <sub>2</sub> O <sub>3</sub> 0.25%	0.35 μm

### 2.2 Sample Size Estimation

Sample size was calculated a priori using GraphPad StatMate v2.00, based on data from a comparable published study [17]. A minimum of 12 specimens per group was determined to achieve 90% statistical power ( $\beta = 0.10$ ) to detect a clinically meaningful mean difference with a two-tailed significance threshold of  $\alpha = 0.05$ .

### 2.3 Specimen Fabrication

To eliminate the biological variability inherent to natural dental substrates, such as variations in enamel/dentin composition, morphology, and structural integrity, standardized epoxy-resin dies were utilized for the testing framework. Twenty-four standardized all-ceramic crowns were fabricated on epoxy-resin dies representing mandibular right first molar preparation ( $n = 12$  per ceramic group). Tooth preparation was performed by a single experienced operator on a typodont acrylic molar using a custom-made silicone-guided preparation device (REPLISIL 22, Dent-E-Con, Germany) attached to a surveyor (BEGO, Bremen, Germany). Preparation parameters included a 1.2 mm circumferential chamfer finish line, 1.5–2.0 mm occlusal reduction, total occlusal convergence (TOC) of 20°, and a minimum occluso-cervical height of 4–5 mm. A silicone index (Optosil, Germany) was created before the preparation to standardize tissue reduction amounts.

Impressions were taken with addition-silicone material (Imprint II, 3M ESPE, USA) and poured in epoxy-resin (Chema-poxy 150, CMB Chemicals, Egypt) to produce 24 identical standardized dies, allowed to set for 24 hours prior to use.

### 2.4 Digital Workflow: Scanning, Design, and Fabrication

Die surfaces were dried and coated with scanning spray (Dentify GmbH, Germany), then digitally scanned using a 3D optical laboratory scanner (NeWay, Open Technologies, Italy). The resulting STL data were transferred to Exocad software (Exocad GmbH, Germany) for coping design. During the CAD phase, virtual restorations were designed with strictly standardized cement space settings (40 μm) to replicate realistic clinical parameters. Frameworks were designed with standardized wall thicknesses of 0.3 mm for NANOZR and 0.5 mm for Y-TZP, in strict accordance with their respective manufacturers' clinical design guidelines for posterior crowns. To prevent wear-induced inaccuracies and micro-cracking that could compromise marginal adaptation, Dedicated cutting burs were replaced after milling each framework.

CAD data were exported to CAM software (Millbox v3.7.3, Roland DG Corp., Japan) and milled using a five-axis milling machine (DWX-52D, Roland DG Corp., Japan), with dedicated cutting burs replaced for each framework. Milled frameworks were steam-cleaned and sintered on alumina beads: NANOZR at 1500°C for 2 hours and Y-TZP at 1450°C for 2 hours (YENADENT Tegra Speed 1600, France).

### 2.5 Veneering and Cementation

All frameworks were veneered with feldspathic porcelain (VITA VM9, VITA Zahnfabrik, Germany) by conventional layering technique using a single trained dental technician. Dentin and enamel layers were fired at 900°C (Programat EP 3000, Ivoclar Vivadent, Liechtenstein), and final glazing was applied with VITA Akzent at 900°C for 1 minute.

Internal surfaces of the restorations and the corresponding dies were treated strictly according to the manufacturers' protocols (airborne-particle abrasion with 50 μm Al<sub>2</sub>O<sub>3</sub>). To ensure uniform cement film thickness and eliminate operator-induced seating discrepancies, all restorations were cemented under a standardized static load of 5 kg using a custom-made,

electro-hydraulically controlled specimen holding device for a specified duration for 5 minutes prior to light-curing.

Internal crown surfaces were sandblasted with 50 µm Al<sub>2</sub>O<sub>3</sub> particles (2 bar; 5 seconds), ultrasonically cleaned in ethanol (60 seconds), and steam-cleaned (60 seconds). Internal surfaces were then salinized (Ceramic Primer II, GC, Japan). Die surfaces were etched with 40% phosphoric acid (1 minute), rinsed, and air-dried. Crowns were luted with dual-cure self-adhesive resin cement (G-Cem, GC, Japan) under a 5 kg standardized seating load for 5 minutes. Excess cement was removed and light-curing was performed for 40 seconds per surface (Elipar LED unit, 3M ESPE, Germany). Specimens were kept in 37°C distilled water for a minimum of 24 hours.

### 2.6 Thermomechanical Aging Simulation

Thermo-mechanical aging was performed utilizing a four-station ROBOTA chewing simulator (Model ACH-09075DC-T, AD-Tech., Germany) with integrated thermocycling. Specimens underwent 150,000 masticatory cycles under a 50 N vertical load (frequency: 1.2 Hz). Simultaneously, the integrated thermocycling system executed 1,500 thermal cycles between water baths of 5 °C and 55 °C (ISO 11405 standard), with a dwell time of 30 seconds in each bath and a transfer time of 10 seconds [18].

### 2.7 Marginal Gap Measurement

Marginal gap measurements were performed before and after thermo-mechanical aging using a stereomicroscope at 45× magnification. For each crown, standardized digital images were captured along the crown–die interface. Twenty equidistant points were selected around the entire crown margin, and the marginal gap was measured as the vertical distance between the crown margin and the corresponding finish line of the die. Measurements were performed using ImageJ software, and the mean marginal gap value for each crown was calculated and used for statistical analysis.

### 2.8 Statistical Analysis

Statistical analyses were accomplished using SPSS v23.0 (IBM Corp., USA). Normality was verified utilizing the Shapiro-Wilk test. Marginal gap data were expressed as mean ± standard deviation (SD). The effect of material type and thermo-mechanical aging on marginal gap values was analyzed using two-way repeated-measures analysis of variance (ANOVA). Pairwise comparisons were conducted with Bonferroni correction; the level of significance was set at α = 0.05. Within-group pre- and post-aging comparisons were conducted utilizing paired t-tests, and across-group comparisons at every time point were performed using independent t-tests.

## 3. RESULTS

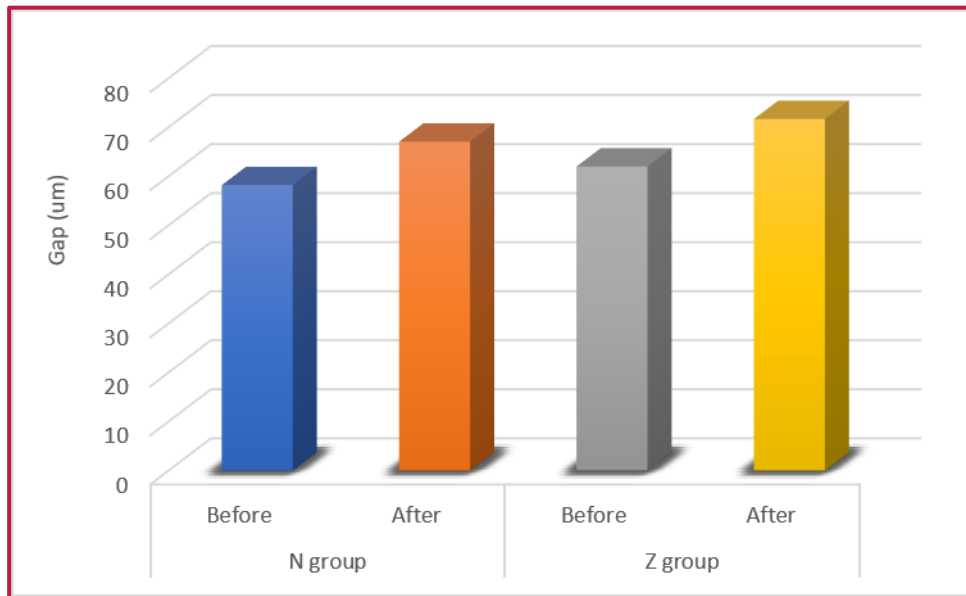
### 3.1 Within-Group Effect of Thermo-Mechanical Aging

Both ceramic systems demonstrated a statistically significant increase in marginal gap following thermo-mechanical aging (Table 2). The NANOZR group recorded a mean marginal gap of 59.22 ± 6.82 µm prior to aging, which increased significantly to 68.01 ± 4.26 µm following aging (paired t-test: p = 0.002). Similarly, the Y-TZP group exhibited an increase from 61.99 ± 9.02 µm to 71.62 ± 5.23 µm (p = 0.006). These findings are illustrated in Figure 1 and summarized in Table 2.

**Table 2: Within-group marginal gap values (Mean ± SD, µm) before and after thermo-mechanical aging**

Group	Time Point	Mean ± SD (µm)	Min (µm)	Max (µm)	95% CI Low	95% CI High	p-value
NANOZR	Prior to aging	59.22 ± 6.82	44.64	63.79	53.31	61.03	0.002*
NANOZR	Following aging	68.01 ± 4.26	61.93	73.92	63.62	68.49	
Y-TZP	Prior to aging	61.99 ± 9.02	51.53	75.34	56.83	67.18	0.006*
Y-TZP	Following aging	71.62 ± 5.23	61.46	82.87	68.64	74.68	

\* Statistically significant (p < 0.05); paired t-test



**Figure 1.** Mean marginal gap values (µm) for both ceramic groups at baseline and following thermo-mechanical aging.

### 3.2 Between-Group Comparison Before Aging

Prior to thermo-mechanical aging, no statistically significant difference in marginal gap was detected between the two ceramic systems (NANOZR:  $59.22 \pm 6.82 \mu\text{m}$ ; Y-TZP:  $61.99 \pm 9.02 \mu\text{m}$ ; independent t-test:  $p = 0.281$ ), as depicted in **Table 3** and illustrated in **Figure 1**.

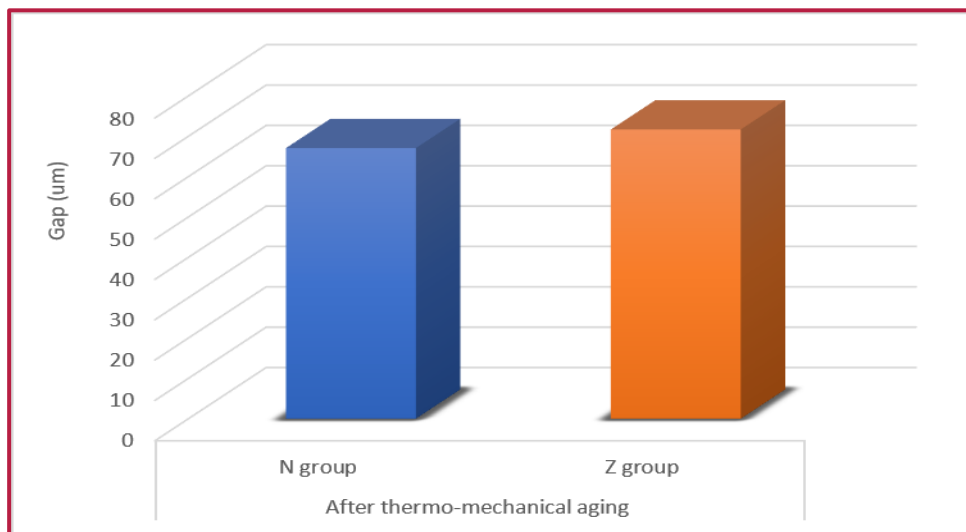
**Table 3: Between-group marginal gap comparison before and after thermo-mechanical aging**

Comparison	NANOZR (Mean ± SD)	Y-TZP (Mean ± SD)	Statistical Test	p-value	Significance
Before aging	$59.22 \pm 6.82 \mu\text{m}$	$61.99 \pm 9.02$	Independent t-test	0.281	NS
After aging	$68.01 \pm 4.26 \mu\text{m}$	$71.62 \pm 5.23 \mu\text{m}$	Independent t-test	0.035	Significant*

\* Statistically significant ( $p < 0.05$ ); NS = non-significant

### 3.3 Between-Group Comparison After Aging

Following thermo-mechanical aging, the Y-TZP group exhibited a significantly greater marginal gap than the NANOZR group ( $71.62 \pm 5.23 \mu\text{m}$  vs.  $68.01 \pm 4.26 \mu\text{m}$ ; independent t-test:  $p = 0.035$ ), as summarized in **Table 3** and illustrated in



**Figure 2.** Comparison of mean marginal gap (µm) between NANOZR and Y-TZP groups following thermo-mechanical aging.

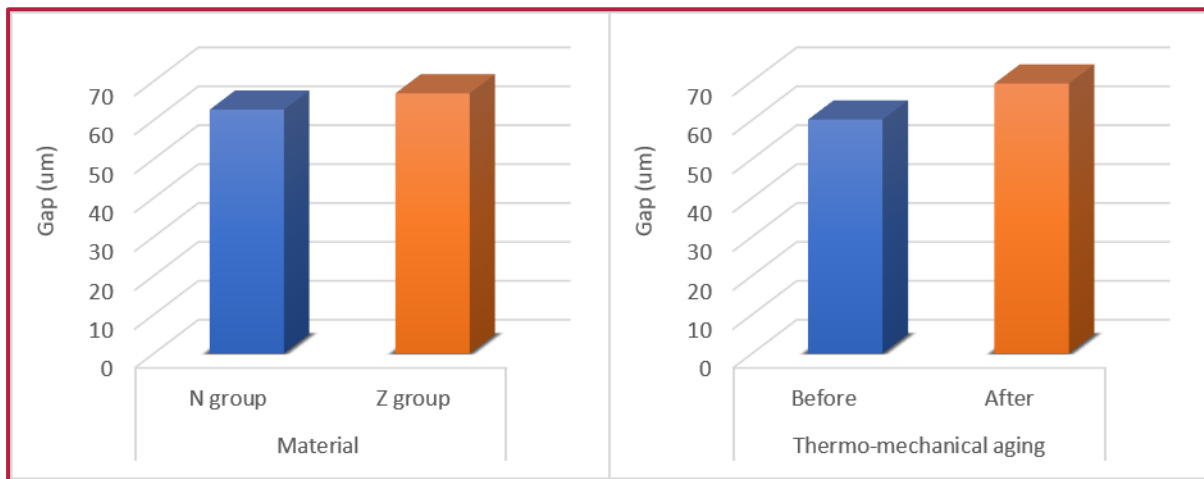
### 3.4 Overall Effects: Repeated-Measures ANOVA

The overall effect of material type on marginal gap, irrespective of aging status, was non-significant (NANOZR:  $62.66 \pm 5.58 \mu\text{m}$ ; Y-TZP:  $66.85 \pm 7.13 \mu\text{m}$ ;  $p = 0.070$ ). In contrast, the overall effect of thermo-mechanical aging, irrespective of material, was highly significant (before:  $60.05 \pm 7.92 \mu\text{m}$ ; after:  $69.39 \pm 4.73 \mu\text{m}$ ;  $p < 0.0001$ ), as presented in **Table 4** and illustrated in **Figure 3**.

**Table 4: Overall effects of material type and aging on marginal gap (repeated-measures ANOVA)**

Factor	Level	Mean $\pm$ SD ( $\mu\text{m}$ )	p-value	Significance
Material type	NANOZR	$62.66 \pm 5.58$	0.070	NS
Material type	Y-TZP	$66.85 \pm 7.13$		
Thermo-mechanical aging	Before	$60.05 \pm 7.92$	$< 0.0001$	Significant*
Thermo-mechanical aging	After	$69.39 \pm 4.73$		

\* Statistically significant ( $p < 0.05$ ); NS = Non-significant



**Figure 3. Bar charts illustrating the overall main effects: total mean marginal gap by material type and total mean marginal gap by aging status.**

## 4. DISCUSSION

The present investigation was designed to evaluate and compare the marginal accuracy of two contemporary zirconia-based all-ceramic crown systems, NANOZR (Ce-TZP/Al<sub>2</sub>O<sub>3</sub>) and Y-TZP, before and after simulated thermo-mechanical aging. Both systems produced clinically acceptable marginal gaps throughout the study, consistently remaining below the 120  $\mu\text{m}$  thresholds commonly cited as clinically acceptable in the fixed prosthodontic literature. [15] The null hypothesis was partially rejected: no significant inter-material difference existed prior to aging, but a statistically significant divergence was identified following aging.

Ceramics play an increasingly important role in prosthodontic rehabilitation owing to their desirable combination of biocompatibility, dimensional stability, and aesthetics. Nevertheless, given their relatively recent introduction compared with traditional metal-ceramic systems, the body of long-term evidence supporting their clinical durability continues to grow [19, 20]. Assessing marginal adaptation with precision is particularly important for ceramic restorations, as marginal discrepancies facilitate microleakage, luting agent dissolution, and secondary caries development [14].

In the current study, stereomicroscopy at 45 $\times$  magnification was selected as the measurement modality, combined with digital image analysis (ImageJ). This methodology is non-destructive, reproducible, and widely applied for in vitro marginal gap assessment, enabling pre- and post-aging comparison at an identical anatomical landmark [21]. Twenty measurement points per crown were selected to provide adequate marginal gap assessment, as recommended for in vitro marginal gap studies [21]. Epoxy-resin standardized dies were employed to eliminate the variability in tooth morphology, mineralisation, and structural integrity inherent to natural dental substrates [22-24].

The finding that both ceramic systems demonstrated significantly increased marginal gap values following thermo-mechanical aging is consistent with the published literature. Thermo-mechanical loading induces multiple degradative mechanisms at the crown-die interface: differential thermal expansion coefficients among the ceramic, luting resin cement, and die substrate; resin cement film degradation and possible interfacial washout during thermal cycles; and fatigue-mediated propagation of interfacial microcracks [25–27]. These mechanisms may explain the measurable increase in marginal discrepancy observed post-aging in both groups, in agreement with the findings of Hasaneen and Mogahed [26] and Sumanth et al. [28]

The significantly greater marginal gap observed for Y-TZP relative to NANOZR specifically following thermo-mechanical aging supports the hypothesis that the nanocomposite microstructure of NANOZR confers distinct aging resistance. The intergranular interpenetrating architecture — in which nano-scale  $\text{Al}_2\text{O}_3$  particles are distributed both within and among Ce-TZP grains — suppresses the tetragonal-to-monoclinic phase transformation that underlies LTD in Y-TZP [29,30]. This structural arrangement creates sub-grain boundaries that resist impurity diffusion and grain boundary weakening, effectively stabilising the ceramic matrix under hydrothermal stress [29]. In Y-TZP, by contrast, the trivalent character of the  $\text{Y}_2\text{O}_3$  stabiliser introduces oxygen vacancies that facilitate diffusion of water species into the ceramic lattice at significantly higher rates than in  $\text{CeO}_2$ -stabilized systems [31]. These findings are corroborated by several prior investigations demonstrating superior phase stability of NANOZR under extended aging conditions [31,32].

Prior to aging, the absence of a statistically significant inter-group difference in marginal gap ( $p = 0.281$ ) suggests that both CAD/CAM-fabricated systems achieve comparable initial marginal accuracy, attributable to the precision of the milling and sintering processes employed. This finding aligns with reports by Güngör et al. [15] who documented comparable marginal fitness for CAD/CAM-fabricated posterior all-ceramic crowns prior to clinical loading.

The practical clinical relevance of these findings lies in the marginal superiority of NANOZR following aging simulation. Although the absolute inter-group difference post-aging was modest (approximately  $3.6 \mu\text{m}$ ), the statistically significant divergence in favour of NANOZR — together with the mechanistic basis of LTD resistance — supports consideration of this nanocomposite ceramic for clinical scenarios in which long-term marginal integrity is of particular concern, such as in patients with elevated caries risk or in restorations with limited accessibility for maintenance.

Contrary to the current results, Monaco et al. [27] reported no significant alteration in marginal adaptation for Y-TZP following thermocycling and mechanical loading. However, the methodological differences between that investigation and the present study are substantial: Monaco et al. utilised extracted natural premolars as abutments, metal-ceramic crowns as comparators, and a different loading protocol. The use of natural teeth introduces biological variability in enamel and dentine composition, preparation geometry, and bonding characteristics that may attenuate the measurable impact of aging on marginal gap. The use of standardized epoxy-resin dies in the present study eliminates this confounding factor, arguably providing greater internal validity for detecting material-specific aging effects.

It should also be noted that marginal adaptation is not governed by the ceramic material alone but may be affected by several methodological and design-related factors. Differences in computer-aided imaging and measurement approaches can influence the reported marginal fitness values [33]. Similarly, crown design parameters, including occlusal thickness, have been shown to affect the mechanical behavior of zirconia restorations [34]. The sequential CAD/CAM fabrication steps may also contribute to changes in the marginal adaptation of zirconia-based crowns [35]. Previous work on digitally fabricated definitive composite and CAD/CAM restorative crowns has also emphasized the importance of evaluating marginal adaptation together with fracture resistance when assessing the overall performance of restorative materials [36]. These considerations are consistent with the broader understanding that oxide ceramic restorations are influenced by material composition, processing conditions, and restoration design [37].

Many limitations of the current research should be recognized. First, the *in vitro* nature of the design inherently limits the direct clinical extrapolation of the findings. The oral cavity presents a complex and dynamic environment characterized by fluctuating thermal, physical, and chemical challenges that are difficult to fully replicate under simplified laboratory conditions. Consequently, long-term *in vivo* clinical trials remain necessary to confirm these results. Second, this investigation was restricted to only two specific brands of zirconia-based ceramic systems, which may limit the generalizability of the outcomes to the wider array of commercial restorative materials currently available on the market. Third, the coping thickness was not identical between the two ceramic groups ( $0.3 \text{ mm}$  for NANOZR vs.  $0.5 \text{ mm}$  for Y-TZP). Although this design choice was necessary to evaluate each material under its manufacturer-recommended clinical parameters, differences in framework volume may have influenced sintering shrinkage dynamics and crown rigidity, potentially acting as a minor confounding variable in marginal adaptation.

## 5. CONCLUSIONS

The subsequent conclusions can be made within the constraints of the current in vitro study:

- Both NANOZR and Y-TZP all-ceramic crowns showed marginal discrepancy values within the clinically acceptable range.
- Thermo-mechanical aging increased the marginal gap in both ceramic systems.
- Before aging, the marginal gap values of the two materials were comparable; however, after aging, NANOZR showed lower marginal discrepancy than Y-TZP.

## REFERENCES

- [1] Hemdan S, El-Sharkwy Z. Comparative study between monolithic translucent zirconia (Y-TZP) and IPS Empress 2 in marginal fit and fracture strength. *Al-Azhar Dent J Girls*. 2019;6(4):391-399.
- [2] Asharaf S, Karthigeyan AS, Deivanai M, Mani R. Zirconia: properties and application - a review. *Pak Oral Dent J*. 2014;34(1):178-183.
- [3] Fernandes NA, Vally ZI, Sykes LM. The longevity of restorations - a literature review. *S Afr Dent J*. 2015;70(9):410-413.
- [4] Jang GW, Kim HS, Choe HC, Son MK. Fracture strength and mechanism of dental ceramic crown with zirconia thickness. *Procedia Eng*. 2011;10:1556-1560.
- [5] Rekow ED, Silva NRFA, Coelho PG, Zhang Y, Guess P, Thompson VP. Performance of dental ceramics: challenges for improvements. *J Dent Res*. 2011;90(8):937-952.
- [6] Zhang F, Vanmeensel K, Inokoshi M, Batuk M, Hadermann J, Van Meerbeek B, et al. Critical influence of alumina content on the low-temperature degradation of 2-3 mol% yttria-stabilized TZP for dental restorations. *J Eur Ceram Soc*. 2015;35(2):741-750.
- [7] Okuda Y, Noda M, Kono H, Miyamoto M, Sato H, Ban S. Radio-opacity of core materials for all-ceramic restorations. *Dent Mater J*. 2010;29(1):35-40.
- [8] Tanaka S, Takaba M, Ishiura Y, Kamimura E, Baba K. A 3-year follow-up of ceria-stabilized zirconia/alumina nanocomposite (Ce-TZP/A) frameworks for fixed dental prostheses. *J Prosthodont Res*. 2015;59(1):55-61.
- [9] Kawai Y, Uo M, Wang Y, Kono S, Ohnuki S, Watari F. Phase transformation of zirconia ceramics by hydrothermal degradation. *Dent Mater J*. 2011;30(3):286-292.
- [10] Kim HT, Han JS, Yang JH, Lee JB, Kim SH. The effect of low temperature aging on the mechanical property and phase stability of Y-TZP ceramics. *J Adv Prosthodont*. 2009;1(3):113-117.
- [11] Nishizaki M, Komasa S, Taguchi Y, Nishizaki H, Okazaki J. Bioactivity of NANOZR induced by alkali treatment. *Int J Mol Sci*. 2017;18(4):706.
- [12] Ban S, Sato H, Suehiro Y, Nakanishi H, Nawa M. Biaxial flexure strength and low temperature degradation of Ce-TZP/Al<sub>2</sub>O<sub>3</sub> nanocomposite and Y-TZP as dental restoratives. *J Biomed Mater Res B Appl Biomater*. 2008;87(2):492-498.
- [13] Sato H, Yamada K, Pezzotti G, Nawa M, Ban S. Mechanical properties of dental zirconia ceramics changed with sandblasting and heat treatment. *Dent Mater J*. 2008;27(3):408-414.
- [14] El Basha SH, Hassanien EEY, Elnaggar GA. Novel technique in detecting marginal adaptation of all-ceramic restoration after cementation: case report. *Bull Natl Res Cent*. 2023;47(1):1-6.
- [15] GÜNGÖR MB, DOĞAN A, BAL BT, NEMLİ SK. Evaluation of marginal and internal adaptations of posterior all-ceramic crowns fabricated with chair-side CAD/CAM system: an in vitro study. *Acta Odontol Turc*. 2018;35(1):1-8.
- [16] Tekin YH, Hayran Y. Fracture resistance and marginal fit of the zirconia crowns with varied occlusal thickness. *J Adv Prosthodont*. 2020;12(5):283-290.
- [17] Nakamura T, Sugano T, Usami H, Wakabayashi K, Ohnishi H, Sekino T, et al. Fitting accuracy and fracture resistance of crowns using a hybrid zirconia frame made of both porous and dense zirconia. *Dent Mater J*. 2015;34(2):257-262.
- [18] Nawafleh N, Hatamleh M, Elshiyab S, Mack F. Lithium disilicate restorations fatigue testing parameters: a systematic review. *J Prosthodont*. 2016;25(2):116-126.
- [19] Bankoğlu GÜNGÖR M, YILMAZ H, AYDIN C, KARAKOCA NEMLİ S, TURHAN BAL B, TIRAŞ T. Biaxial flexural strength and phase transformation of Ce-TZP/Al<sub>2</sub>O<sub>3</sub> and Y-TZP core materials after thermocycling and mechanical loading. *J Adv Prosthodont*. 2014;6(3):224-232.
- [20] Pereira RM, Ribas RG, Montanheiro TLDA, Schatkoski VM, Rodrigues KF, Kito LT, et al. An engineering perspective of ceramics applied in dental reconstructions. *J Appl Oral Sci*. 2023;31:e20220421.
- [21] Groten M, Axmann D, Pröbster L, Weber H. Determination of the minimum number of marginal gap measurements required for practical in vitro testing. *J Prosthet Dent*. 2000;83(1):40-49.
- [22] Naffah N, Ounsi H, Ozcan M, Bassal H, Salameh Z. Evaluation of the adaptation and fracture resistance of three CAD/CAM resin ceramics: an in vitro study. *J Contemp Dent Pract*. 2019;20(5):571-576.

- [23] Alammari MR, Abdelnabi MH, Swelem AA. Effect of total occlusal convergence on fit and fracture resistance of zirconia-reinforced lithium silicate crowns. *Clin Cosmet Investig Dent*. 2019;11:1-8.
- [24] Li M, Komasa S, Hontsu S, Hashimoto Y, Okazaki J. Structural characterization and osseointegrative properties of pulsed laser-deposited fluorinated hydroxyapatite films on nano-zirconia for implant applications. *Int J Mol Sci*. 2022;23(5):2416.
- [25] Sadighpour L, Geramipanah F, Fazel A, Allahdadi M, Kharazifard MJ. Effect of selected luting agents on the retention of CAD/CAM zirconia crowns under cyclic environmental pressure. *J Dent*. 2018;15(2):97-105.
- [26] Hasaneen FA, Mogahed MM. Comparative in vitro study of marginal gap of four CAD/CAM all-ceramic systems with thermal aging. *Tanta Dent J*. 2021;18(1):12-19.
- [27] Monaco C, Rosentritt M, Llukacej A, Baldissara P, Scotti R. Marginal adaptation, gap width, and fracture strength of teeth restored with different all-ceramic vs metal-ceramic crown systems: an in vitro study. *Eur J Prosthodont Restor Dent*. 2016;24(3):130-137.
- [28] Sumanth KS, Poovani S, Sonnahalli NK. Evaluation of effect of fabrication steps on marginal adaptation of CAD/CAM zirconia-based crowns in comparison to sintered PFM crowns: an in vitro study. *Int J Prosthodont Restor Dent*. 2020;10(4):151-157.
- [29] Ban S. Classification and properties of dental zirconia as implant fixtures and superstructures. *Materials (Basel)*. 2021;14(17):4879.
- [30] Chevalier J, Gremillard L, Deville S. Low-temperature degradation of zirconia and implications for biomedical implants. *Annu Rev Mater Res*. 2007;37:1-32.
- [31] Arena A, Prete F, Rambaldi E, Bignozzi MC, Monaco C, Di Fiore A, et al. Nanostructured zirconia-based ceramics and composites in dentistry: a state-of-the-art review. *Nanomaterials (Basel)*. 2019;9(10):1393.
- [32] Ban S, Nawa M, Suehiro Y, Nakanishi H. Mechanical properties of zirconia/alumina nanocomposite after soaking in various water-based conditions. *Key Eng Mater*. 2006;309-311:1219-1222.
- [33] Salem ZM, Shakal MAA, El-Dessouky RA. Comparative evaluation of the marginal fitness of vonlay nanoceramic hybrid restorations using different computer-aided imaging techniques: an in vitro study. *Tanta Dent J*. 2023;20(1):20-26.
- [34] Sorrentino R, Triulzio C, Tricarico MG, Bonadeo G, Gherlone EF, Ferrari M. In vitro analysis of the fracture resistance of CAD/CAM monolithic zirconia molar crowns with different occlusal thickness. *J Mech Behav Biomed Mater*. 2016;61:328-333.
- [35] El-Dessouky RA, Salama MM, Shakal MA, Korsel AM. Marginal adaptation of CAD/CAM zirconia-based crown during fabrication steps. *Tanta Dent J*. 2015;12(2):81-88.
- [36] Salem ZM, Shakal MAA, El-Dessouky RA. Comparative evaluation of the marginal fitness of vonlay nanoceramic hybrid restorations using different computer-aided imaging techniques: an in vitro study. *Tanta Dent J*. 2023;20(1):20-26.
- [37] Piconi C, Sprio S. Oxide bioceramic composites in orthopedics and dentistry. *J Compos Sci*. 2021;5(8):207.