BEYOND GENERATIONS: A NEW CLINICAL CLASSIFICATION OF ZIRCONIA FOR PROSTHETIC DENTISTRY

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Abstract

Background: Zirconium dioxide is widely used in prosthetic dentistry due to its high strength, durability, and biocompatibility. However, its clinical performance may be compromised by fracture susceptibility under certain conditions. In addition, inconsistencies in fabrication protocols and processing recommendations contribute to variability in outcomes and limit standardized clinical application. Selection of appropriate zirconia for prosthodontic applications remains challenging for clinicians and dental technicians due to the lack of a universally accepted, clinically relevant classification system. Existing classifications, mainly based on composition or generation, provide limited guidance for everyday clinical decision-making.

Aim: The primary aim of this study is to develop a clinically relevant and practically applicable classification system for zirconium dioxide in prosthetic dentistry. This classification will be based on parameters directly linked to clinical decision-making, with the objective of providing clear guidance for material selection in specific indications. Furthermore, the study aims to support this classification through experimental evaluation, thereby enhancing the predictability, reliability, and long-term clinical success of zirconia-based prosthetic restorations.

Methods: A total of 80 pre-sintered Y-TZP specimens composed of synthesized zirconium dioxide stabilized with yttria (Y_2O_3) were prepared for experimental evaluation. All samples were subjected to a three-point bending test to determine flexural strength. Following mechanical testing, samples underwent macroscopic and microscopic examination to assess fracture patterns and surface characteristics. In the subsequent stage, detailed microstructural analysis was performed using scanning electron microscopy at magnifications of up to 1000×, enabling visualization of structural alterations induced by the applied mechanical stress. Additionally, phase composition and structural changes were evaluated through qualitative and quantitative X-ray diffraction analysis. All procedures complied with the requirements of ISO 6872:2008.

Results: Three-point bending tests showed variability in flexural strength among Y-TZP specimens, indicating a clear dependence on material processing and microstructural characteristics. SEM analysis confirmed differences in grain structure, porosity, and surface morphology, while XRD revealed variations in phase composition, including tetragonal–monoclinic transformation. These structural and phase differences were directly associated with mechanical performance. Based on the experimental findings and comprehensive literature analysis, a clinically oriented classification system of zirconia (Y-TZP) was developed, integrating mechanical properties, structural characteristics, and indication-specific requirements. This classification is structured according to practical clinical criteria, including mechanical performance, indication-specific requirements, and processing-related factors.

Conclusions: The study demonstrates that zirconia performance is strongly influenced by its microstructure and phase composition, directly affecting clinical reliability. The proposed clinical classification of zirconia (Y-TZP) provides a practical framework for material selection based on functional and indication-related criteria. This classification may improve decision-making in prosthetic dentistry and support more predictable clinical outcomes in zirconia-based restorations. (**TCM-GMJ August 2026; 11 (3): P39-P43)**

Keywords: Zirconium Dioxide (Y-TZP), Prosthetic Dentistry, Modern Classification of Zirconia, Flexural Strength.

Introduction

The widespread use of zirconium dioxide in prosthodontic restorations has highlighted its principal limitations, most notably fracture of monolithic (full-contour) zirconia restorations and delamination or chipping of the veneering porcelain layers in bilayer constructions (1)(2). Despite the material's excellent mechanical properties and biocompatibility, these failure modes remain clinically relevant and are frequently linked to the mechanical and thermal treatments applied during laboratory processing and chairside adjustment(3)(4)(5). At the same time, considerable inconsistency persists between manufacturers' recommendations and the actual practices of dental technicians regarding the optimal execution of these technological procedures.

Surface sandblasting of zirconia is routinely performed to increase surface roughness and thereby enhance the bonding of veneering ceramics (6)(7)(8). Internal surface sandblasting is similarly employed to improve adhesion between the restoration and the prepared tooth structure (9). For the accurate seating of fully sintered zirconia restorations—whether monolithic or framework-supported—adjustments using fine-grit diamond burs under water cooling are frequently required (9)(10). Following such adjustments, a so-called "regeneration firing"

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or heat treatment is commonly recommended to restore the material's properties (9)(11)(18).

However, the scientific literature remains divided regarding the effects of these procedures. Some authors suggest that abrasive blasting may induce a tetragonal-to-monoclinic (T→M) phase transformation, resulting in localized volumetric expansion and the formation of microcracks that may influence crack propagation (12)(13)(17). In contrast, it has been proposed that subsequent high-temperature annealing may reverse this phase transformation, relieve residual stresses, and potentially affect crack development in a different manner (14)(15)(16).

Fracture of ceramic materials may originate from a single critical microstructural defect or from the accumulation and coalescence of multiple defects (12)(18)(19). In clinical applications, the primary concern is the resistance of materials to elastic deformation and to crack initiation and propagation (11)(20)(22). Despite the widespread clinical use of zirconia-based materials, there is still no universally accepted classification system that enables clear, clinically oriented selection of zirconium dioxide types for prosthodontic applications(21)(23). Existing classifications, often based on generational or compositional criteria, are insufficiently aligned with practical clinical decision-making. This issue is particularly pronounced in regions where education in dental materials science is limited.

In routine clinical practice, practitioners are required to make rapid yet accurate material selections across a wide range of clinical situations, which further emphasizes the need for a simplified and standardized classification system. Therefore, the development of a modern, clinically oriented classification of zirconium dioxide _ specifically adapted for prosthodontic use would significantly improve decision-making in both clinical and dental laboratory settings, ensuring more predictable and appropriate material selection. Despite the wide clinical use of Y-TZP ceramics, there is currently no universally accepted classification that clearly links material properties with appropriate clinical indications. Existing classification approaches, which are predominantly based on generational or compositional differences, do not sufficiently support daily clinical decision-making. As a result, clinicians and dental technicians are often required to select materials without a structured decision framework, which may contribute to inconsistent outcomes, particularly in complex prosthodontic cases.

A clinically oriented classification system for zirconia would therefore be of high practical value. Such a system would facilitate faster and more evidence-based material selection, improve communication between clinicians and laboratories, and reduce variability in treatment outcomes. Moreover, integrating mechanical performance, phase stability, and processing sensitivity into a unified classification would directly support safer and more predictable clinical application of zirconia-based restorations.

Methods

For the purposes of this study, yttria-stabilized tetragonal zirconium dioxide (Y-TZP) specimens were prepared from pre-sintered zirconia blocks (VITA In-Ceram YZ Cubes for inLab, VITA Zahnfabrik). A total of 80 blocks were milled, after which final sintering was performed in a VITA ZYRCOMAT® 6100 MS furnace (VITA Zahnfabrik, Germany) according to the manufacturer's protocol. Following sintering, the samples were examined under a light microscope, and 50 defect-free specimens with standardized dimensions (accuracy ±0.01 mm) were selected for further investigation.

The selected specimens were randomly divided into five experimental groups (n = 10 per group), as follows:

- Group SB: Sandblasting only, without subsequent heat treatment.
- Group SBS: Sandblasting followed by regeneration firing.
- Group D: Mechanical adjustment using a diamond bur without additional heat treatment.
- Group DS: Diamond bur treatment followed by regeneration firing.
- Group C (Control): No mechanical or thermal treatment applied.

Sandblasting was performed using 110 μm Al_2O_3 particles for 10 seconds, at a distance of 1 cm, under a pressure of 3 bar. Diamond bur treatment was carried out using a zirconia-specific bur (ZR6850.FG.016 Crown and Bridge, Komet, Germany) under standardized conditions. Regeneration firing, where applied, was performed at 1000°C for 15 minutes, with a total cycle of 25 minutes, starting from 550°C and a heating rate of 100°C/min, according to a standardized protocol. All specimens were ultrasonically cleaned, dried, and verified for dimensional accuracy prior to testing.

All specimens were subjected to a three-point bending test until fracture in order to determine flexural strength. Following fracture, both macroscopic and microscopic examinations of the fracture surfaces were performed to evaluate crack initiation and propagation patterns. Microstructural evaluation was conducted using scanning electron microscopy (Tescan VEGA II, Czech Republic). Observations were performed at magnifications ranging from 250× to 1000× to assess surface morphology and structural alterations induced by mechanical and thermal treatments. Phase composition and structural transformations were analyzed using X-ray diffraction (XRD). Measurements were performed with an X'Pert MRD Pro diffractometer (Malvern Panalytical GmbH, Germany) in accordance with ISO 6872:2008 (Dentistry—Ceramic materials).

XRD analysis is a non-destructive method used to determine both qualitative and quantitative phase composition of crystalline materials. It is based on the diffraction of X-rays by crystal lattices and the interpretation of diffraction peak positions and intensities according to Bragg's law. This allows identification of phase transformations, particularly the tetragonal-to-monoclinic transformation in Y-TZP, as well as quantification of phase distribution after different surface and thermal treatments.

Statistical evaluation of the obtained data was performed using TIBCO Statistica v13 (2022). One-way analysis of variance (ANOVA) was applied to determine statistically significant differences between groups, with a predefined significance level of $p < 0.05$.

As a result of the comparative analysis of the authors' experimental findings, together with existing clinical and laboratory data and accumulated practical experience, a modern, clinically oriented classification of zirconium dioxide was developed to support material selection in prosthodontic practice.

Results and discussion

The results of the present study demonstrated that both sandblasting and sandblasting followed by regeneration firing significantly influence the flexural strength of Y-TZP specimens.

After sandblasting, the mean flexural strength increased to 1253.67 MPa. However, when sandblasting was followed by regeneration firing, a pronounced reduction in strength was observed, with a mean value of 744.96 MPa. In contrast, no statistically significant difference was detected between the control group and the specimens treated with a diamond bur. The mean flexural strength values were 1062.67 MPa (control) and 1061.12 MPa (diamond bur group), respectively. Nevertheless, when diamond bur–treated specimens were subsequently subjected to regeneration firing, a decrease in strength was observed, with a mean value of 951.47 MPa.

Overall, the comparative analysis of the results indicates a clear trend in the mechanical behavior of yttria-stabilized tetragonal zirconium dioxide (Y-TZP): surface sandblasting initially increases flexural strength, whereas subsequent regeneration firing leads to a significant reduction in strength. Diamond bur treatment alone does not produce a meaningful change in mechanical performance; however, a tendency toward strength reduction after thermal treatment was also observed.

SEM analysis at 1000× magnification demonstrated a generally homogeneous and dense microstructure in the control group (C), diamond bur group (D), and diamond bur with regeneration firing group (DS). In contrast, the sandblasted and subsequently heat-treated group (SBS) exhibited localized microstructural irregularities, including minor voids distributed within the material. These voids are likely associated with sequential phase transformations and volumetric changes related to the tetragonal-to-monoclinic (t→m) transformation induced by mechanical treatment, followed by partial reverse transformation (m→t) during heat treatment, resulting in localized structural instability.

Quantitative phase analysis revealed the following changes in monoclinic phase content:

- Control group: approximately 0.1% monoclinic phase
- Sandblasting (SB): increase to approximately 8% monoclinic phase
- Sandblasting + regeneration firing (SBS): reduction to approximately 1.5% monoclinic phase
- Diamond bur treatment (D): increase to approximately 3% monoclinic phase
- Diamond bur + regeneration firing (DS): return to baseline level of approximately 0.1% monoclinic phase

These results confirm that mechanical surface treatment induces a measurable tetragonal-to-monoclinic (t→m) phase transformation, whereas subsequent regeneration firing partially or fully reverses this transformation, depending on the type of initial mechanical intervention.

The present study demonstrates that mechanical and thermal treatments of zirconia significantly influence both its phase composition and mechanical properties. Sandblasting markedly increases flexural strength, an effect attributable to transformation toughening associated with the tetragonal-to-monoclinic (t→m) phase transformation. However, subsequent regeneration firing reverses this strengthening mechanism by reducing monoclinic phase content, resulting in a significant decrease in strength. In contrast, preparation with a diamond bur alone does not significantly affect mechanical performance, although thermal treatment following this procedure may still contribute to strength reduction.

These findings provide a robust foundation for the development of a modern, clinically oriented classification of zirconia (Fig. 1). The proposed system integrates parameters of direct clinical relevance—mechanical behavior, susceptibility to phase transformation, and response to thermal processing—thereby reflecting the material's performance under realistic prosthodontic conditions.

Unlike conventional classifications, which are based primarily on generational or compositional distinctions, the new framework categorizes zirconia according to its expected behavior during laboratory processing and intraoral adjustment. In addition to the chemical designation (e.g., 3Y-TZP), the classification incorporates commercially available material systems from major manufacturers. This dual structure bridges the gap between scientific nomenclature and everyday clinical practice, enhancing usability for both clinicians and dental technicians.

Consequently, the proposed clinical classification offers a simplified, standardized, and evidence-based framework that promotes more predictable material selection, facilitates interdisciplinary communication, and improves the reliability of prosthodontic outcomes in routine practice.

Conclusion

The findings of this study demonstrate that the mechanical behavior and phase stability of Y-TZP are significantly influenced by surface treatment protocols, particularly the combination of abrasive procedures and subsequent thermal processing. These interactions directly affect the clinical performance and long-term reliability of zirconia-based restorations.

From a clinical perspective, the results highlight the necessity of a structured and evidence-based approach to material selection. The observed variability in material response to common laboratory procedures underscores the limitations of existing classification systems, which are often based solely on composition or generational differences and do not adequately reflect clinical behavior.

In this context, the present study provides a scientific foundation for the development of a modern, clinically oriented classification system for zirconium dioxide. Such a classification should integrate key parameters, including mechanical properties, susceptibility to phase transformation, and response to routine clinical and laboratory procedures. This approach allows zirconia materials to be categorized not only by their composition but also by their functional performance under real clinical conditions.

The implementation of a clinically relevant classification system is of substantial practical importance. It facilitates more accurate and efficient material selection, enhances communication between clinicians and dental technicians, and supports a more consistent application of zirconia across a wide range of prosthodontic indications. Ultimately, the adoption of this classification into routine clinical practice will improve predictability of outcomes, optimize the use of modern zirconia materials, and contribute to higher standards of care in prosthodontics.

	Anterior/1–2 units	Transitional/ short-span	Posterior/long-span/ full-arch
Enhanced esthetics	**6Y-PSZ** **M6Y-PSZ** NACERA | Pearl Q3 Multi-Shade 6Y-PSZ Ultra High Translucent - Multilayered	**M5Y-PSZ** **5Y-PSZ** Vita | YZ XT Emax Zir CAD | MT Multi 3M LAVA | Lava Esthetic Sagemax | NexxZr Multi: High Translucent Dental Direk | DD cubeX2®–Super HighTranslucent (SHT)	**M3Y-TZP** Vita | YZ HT Cercon | Cercon ht GC | Ultra High Translucency(UHT) Katana | HTML Dental Direk | DD Bio ZX2–High Translucent(HT)
Dual-property	**M4Y-5Y** Katana | UTML Katana | YML	**M3Y-5Y** **M3Y-4Y** **M4Y-PSZ** Vita | YZ ST Katana | STML Sagemax | NexxZr T Multi: Translucent Dental Direk | DD cube ONE®–HighTranslucent Plus (HT+)	**3Y-TZP** 3M LAVA | Lava Plus Vita | YZ T Emax Zir CAD | MO GC | High Translucency (HT) Katana | HT Dental Direk | DD Bio Z –High Strength (HS)
High strength & transformation toughening		**4Y-PSZ** Amann Girrbach | Zolid gen x Amann Girrbach | Zolid drs	**3Y-HA TZP** **ATZ** **NanoZR** Amann Girrbach | Ceramill Zi Emax Zir CAD | LT Cercon | Cercon base GC | Standard Translucency (ST) Katana | LT

Fig. 1. A Novel Clinical Decision-Making Classification of Yttria-Stabilized Zirconia (Y-TZP) Based on Mechanical Integrity, Phase Stability, and Laboratory Processing Response

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