# Microstructural Degradation of Zirconia-Lithium Disilicate Bilayer Restorations Under Thermocyclic Fatigue: A Quantitative Fractographic Analysis in the Posterior Dentition


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**Abstract.** Bilayer all-ceramic restorations combining zirconia frameworks with lithium disilicate veneering ceramics are increasingly prescribed for posterior load-bearing zones; however, their long-term cohesive fracture behavior under thermocyclic conditions remains insufficiently characterized. This study evaluated the fractographic profiles and crack propagation patterns in forty-eight bilayer specimens subjected to 10,000 thermocycles (5°C–55°C) combined with axial occlusal loading (200 N). Scanning electron microscopy, energy-dispersive X-ray spectroscopy, and three-dimensional profilometry were employed to quantify delamination depth, radial crack density, and residual stress distribution. Results demonstrated statistically significant correlation between veneer thickness exceeding 1.8 mm and subsurface lateral crack initiation ($p < 0.001$). Phase transformation from tetragonal to monoclinic zirconia was confirmed at interfacial zones. These findings provide clinically actionable thresholds for veneer dimensioning protocols aimed at reducing catastrophic cohesive failure rates in molar-region fixed dental prostheses.

**Keywords:** zirconia-lithium disilicate bilayer, thermocyclic fatigue, fractographic analysis, cohesive veneer fracture, tetragonal-to-monoclinic phase transformation, all-ceramic fixed dental prostheses, occlusal loading simulation, residual stress distribution, delamination crack propagation

## Introduction

Bilayer all-ceramic restorations have become a cornerstone of contemporary restorative dentistry, offering an optimal combination of mechanical resilience and optical translucency that closely mimics the natural dentition. Among the material systems currently in clinical use, zirconia-core restorations veneered with lithium disilicate glass-ceramic have attracted considerable attention due to their superior flexural strength (exceeding 900 MPa at the framework level) and the inherent crystallographic toughening mechanisms associated with stabilized tetragonal zirconia polycrystals (3Y-TZP). Despite these promising mechanical properties, the clinical failure database compiled through systematic reviews published between 2022 and 2025 consistently identifies cohesive veneer fracture—colloquially termed "chipping"—as the predominant mode of long-term restoration breakdown, with incidence rates ranging from 13.6% to 28.4% over five-year observation periods in the posterior dentition. The biomechanical environment of the molar and premolar regions is particularly hostile to ceramic veneering materials. Occlusal forces in these segments routinely exceed 150–400 N in the adult dentition, and the superimposition of thermal cycling associated with dietary intake—spanning a functional temperature range of approximately 0°C to 60°C—generates cyclic tensile stresses at the zirconia-veneer interface through differential coefficients of thermal expansion. When the mismatch in thermal expansion between the zirconia substructure (approximately $10.5 \times 10^{-6}$/°C) and the veneering ceramic (approximately $9.5–10.0 \times 10^{-6}$/°C) is not precisely controlled during the layering and sintering protocol, residual tensile stresses accumulate within the veneer bulk, predisposing the restoration to subsurface lateral crack initiation and subsequent delamination under fatigue loading. From a crystallographic standpoint, the stress-induced tetragonal-to-monoclinic (t→m) phase transformation at the zirconia surface—while conferring transformation toughening in monolithic configurations—has been implicated in volumetric expansion (~3–5%) at the interfacial zone of bilayer constructs, potentially disrupting adhesive continuity with the overlying feldspathic or glass-ceramic veneer. Recent micro-computed tomography and focused ion beam cross-sectional studies have begun to elucidate the spatial relationship between transformation-affected zones and crack origin sites; however, a quantitative fractographic framework correlating veneer geometry, thermocyclic parameters, and crack morphology has yet to be established with sufficient statistical rigor to inform clinical dimensioning guidelines. The present investigation addresses this gap through a controlled in vitro experimental design incorporating standardized bilayer disc specimens subjected to combined thermocyclic and axial fatigue protocols. Fractographic endpoints were quantified using scanning electron microscopy, energy-dispersive X-ray spectroscopy, and three-dimensional surface profilometry. The manuscript is organized as follows: Section 2 describes the specimen fabrication procedures and mechanical testing protocols; Section 3 presents the fractographic and spectroscopic results; Section 4 discusses the clinical implications of veneer thickness thresholds and interfacial stress management strategies; and Section 5 outlines the conclusions and directions for future in vivo validation studies.



## References

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