

Summary

This doctoral research investigates the chemical and structural stability of thermoplastic polymers used in orthodontic clear aligners following intraoral exposure, adopting a translational approach that integrates clinical observation with advanced biomaterials characterization.

Clear aligner therapy represents a paradigmatic example of high-turnover polymeric medical devices, routinely replaced at short intervals despite prolonged daily exposure to the oral environment. While replacement protocols are primarily dictated by orthodontic treatment planning, limited evidence exists regarding the actual chemical condition of these materials at the end of their clinical use. This gap raises a fundamental question: whether aligners are discarded due to true material degradation or simply as a consequence of predefined therapeutic sequencing.

To address this issue, a multimodal analytical framework was implemented, combining Raman spectroscopy, X-ray diffraction (XRD), X-ray fluorescence (XRF), microscopy, and multivariate statistical analysis. Two different categories of aligners—thermoformed and directly 3D-printed—were evaluated at baseline (unused condition) and after clinically relevant intraoral exposure periods of 7 and 14 days. Analyses were performed on anatomically distinct regions subjected to different mechanical loads to account for heterogeneous stress distribution.

Across all analytical techniques, the results consistently demonstrated preservation of molecular composition, structural organization, and surface integrity after intraoral use. Raman spectroscopy revealed no detectable chemical modifications in the polymer backbone, while XRD analysis confirmed the absence of structural rearrangements or crystallization phenomena. Morphological observations further supported the maintenance of surface integrity, with only minor superficial wear not associated with material degradation. Multivariate statistical analysis (PCA) confirmed the absence of significant differences between baseline and post-exposure samples.

These findings indicate that the complex oral environment—characterized by thermal fluctuations, chemical exposure, mechanical loading, and microbial activity—does not induce measurable chemical or structural degradation of the investigated polymers within standard clinical timeframes. The results support the interpretation that aligner replacement is primarily driven by biomechanical treatment progression rather than intrinsic material failure.

From a bioengineering perspective, this work highlights a fundamental distinction between functional ageing and chemical degradation. While clinical performance may evolve due to viscoelastic adaptation or surface interactions, the molecular integrity of the material remains substantially preserved.

Beyond its clinical implications, this study introduces a broader perspective on the lifecycle of polymer-based biomedical devices. The demonstrated stability of aligner materials suggests that the

end of clinical use does not necessarily coincide with the loss of material value. This observation provides a scientific basis for reconsidering current disposal paradigms and supports future investigation into sustainable and circular strategies in biomedical materials engineering.

In conclusion, this research bridges clinical orthodontics and biomaterials science, providing new insights into the in vivo behavior of polymeric medical devices and laying the groundwork for a more sustainable approach to their lifecycle management.