Current understandings in academia emphasize that clear aligners, primarily fabricated from multilayer polymeric sheets such as polyurethane, PET, or PETG, exhibit superior hygiene compared to traditional fixed orthodontic appliances but still accumulate biofilms that contribute to enamel demineralization and gingival inflammation [1]. Despite their relative advantages in maintaining oral hygiene, periodontal studies confirm significant bacterial colonization beneath aligners, underscoring the necessity for effective antimicrobial solutions.

Researchers have extensively investigated various approaches to impart antimicrobial properties to aligners. Nanoparticle coatings have received considerable attention; notably, ZnO and MgO nanoparticle coatings studied by Gharibnavaz et al. demonstrated strong antibacterial effects, although their efficacy substantially diminished (approximately 60-65% retention) within 24 hours of simulated oral conditions and mechanical brushing [1]. Additionally, while ZnO coatings preserved translucency well, MgO coatings posed risks of aesthetic compromise due to discoloration.

Another promising avenue explored by Zhang et al. involved coatings of 4,6-diamino-2-pyrimidine thiol-modified gold nanoparticles (AuDAPT), demonstrating robust antibacterial properties against P. gingivalis, effective biofilm inhibition, and excellent biocompatibility [4]. Similarly, Gramuglia et al. explored quaternary ammonia compounds (QACs) as coatings, effectively reducing bacterial adherence without significantly compromising mechanical properties, although the long-term efficacy of QAC coatings under dynamic oral conditions remains unestablished [5].

Despite advancements, several critical gaps persist. Existing nanoparticle coatings typically lose effectiveness well before the end of standard aligner wear cycles (~7 days). Discoloration, especially associated with MgO coatings, also presents a significant aesthetic challenge. Furthermore, real-world efficacy strongly depends on patient compliance, as highlighted by Giannini et al., pointing toward a gap in developing strategies less reliant on patient hygiene practices [3].

Our proposed solution uniquely addresses these limitations by combining ZnO nanoparticles with AuDAPT nanoparticles into a single hybrid antimicrobial thin film coating applied to PETG or TPU aligners. This dual approach leverages ZnO's proven antibacterial properties and optical clarity, along with AuDAPT's biocompatibility and prolonged effectiveness against biofilm formation. To further enhance durability and maintain effectiveness throughout the standard 7-day aligner cycle, the coating will be stabilized via UV crosslinking, improving resistance to saliva exposure, mechanical abrasion, and brushing.

This innovative combination seeks to overcome the rapid efficacy decline observed with previous nanoparticle coatings, reduce risks of discoloration, and minimize dependency on patient compliance for optimal oral health outcomes. However, potential shortcomings include the need for rigorous clinical validation to ensure consistent long-term performance and to assess any unforeseen biocompatibility or mechanical integrity concerns arising from the hybrid and crosslinked coating strategy.

References:

[1] Gharibnavaz, M., Arash, V., Pournajaf, A., Najafi, F., Rahmati Kamel, M., & Seyedmajidi, S. (2025). Study on the antibacterial properties and optical characteristics of clear orthodontic aligners coated with zinc oxide and magnesium oxide nanoparticles. *Orthodontics & Craniofacial Research*. https://doi.org/10.1111/ocr.12899

[2] Jiang, W. (2025). Effect of bioceramic fillers on antibiofilm and remineralization properties of flowable composite used as clear aligner attachments (T). University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/ubctheses/24/items/1.0448057

[3] Giannini, L., Galbiati, G., Tartaglia, F. C., Grecolini, M. E., Maspero, C., & Biagi, R. (2025). Orthodontic Treatment with Fixed Appliances Versus Aligners: An Experimental Study of Periodontal Aspects. Dentistry Journal, 13(2), 70. https://doi.org/10.3390/dj13020070

[4] Thiruba Suhasini, P., Chakravarthi, S. N. C., Davis, D., Bharathi, E., & Rasiga, G. (2025). Aligner materials and their properties. Cuestiones de Fisioterapia, 54(4). https://doi.org/10.48047/1yhy8771

[5] Gramuglia, V., Makowka, S., Tanberg, W., Zhou, A., Sharma, A., & Al-Jewair, T. (2025). Effect of quaternary ammonium-based antimicrobial coating on the mechanical properties and bacterial adhesion to Gummetal archwire. International Journal of Dentistry, 2025, Article 8157347, 8 pages. https://doi.org/10.1155/ijod/8157347