Cementum-Derived Wnt/β-Catenin Crosstalk in Periodontal Ligament Mechanotransduction: Challenging the Tensional Homeostasis Doctrine in Alveolar Bone Remodeling

Dana Evans
Professor
Tokyo Medical and Dental University
1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8510, Japan

Kai Allen
PhD
Charité – Universitätsmedizin Berlin
Charitéplatz 1, 10117 Berlin, Germany

Robin Hernandez
Associate Professor
Universidade de São Paulo – Faculdade de Odontologia
Av. Professor Lineu Prestes, 2227, Cidade Universitária, São Paulo, SP 05508-000, Brazil

Jordan Anderson
D.Sc
The University of Melbourne – Melbourne Dental School
720 Swanston Street, Carlton, VIC 3053, Australia

Abstract. The tensional homeostasis doctrine has long governed mechanobiological interpretations of periodontal ligament (PDL) adaptation; however, emerging evidence implicates cementum-derived Wnt/β-catenin signaling as an independent regulatory axis that fundamentally uncouples strain-mediated osteoblastogenesis from classical mechanotransduction cascades. This study investigated Wnt ligand secretion profiles in primary human cementoblasts under cyclic compressive loading (0.5–2.5 Hz), integrating RNA sequencing, immunofluorescence co-localization, and finite element modeling of alveolar socket stress distribution. Our findings demonstrate that cementoblast-specific Wnt3a upregulation suppresses RANKL-mediated osteoclastogenesis independently of integrin-focal adhesion kinase pathways, challenging prevailing dogma. These results reframe cementum not merely as an anchorage substrate but as an active mechano-endocrine interface governing periodontal osseous equilibrium, with significant implications for orthodontic force protocols and regenerative periodontal therapy.

Keywords: periodontal ligament mechanotransduction, cementoblast Wnt/β-catenin signaling, alveolar bone remodeling, tensional homeostasis, RANKL-osteoclastogenesis axis, cyclic compressive loading, orthodontic force biomechanics, periodontal regeneration, finite element stress modeling

Introduction

Periodontal tissue homeostasis represents one of the most biomechanically intricate equilibria in the human craniofacial complex, sustained by the continuous cross-regulation of the periodontal ligament (PDL), cementum, and alveolar bone across a lifetime of masticatory and parafunctional loading cycles. Since the formalization of Wolff's Law and its subsequent adaptation to the dento-alveolar apparatus by Frost's mechanostat theory, the prevailing paradigm has held that mechanotransduction within the periodontium is predominantly orchestrated through tensile strain gradients sensed by PDL fibroblasts via integrin–cytoskeletal focal adhesion kinase (FAK) complexes, subsequently relayed to osteoblastic and osteoclastic effector populations. This framework, broadly termed the tensional homeostasis doctrine, has underpinned orthodontic force protocols, implant biomechanical design criteria, and periodontal surgical planning for decades. However, by 2024–2025, converging evidence from single-cell transcriptomics, spatially resolved proteomics, and advanced finite element analyses has begun to expose critical lacunae in this model—most notably, the conspicuous exclusion of cementum as an active mechano-signaling compartment rather than a passive fibrous anchor. Cementum, historically classified as a quiescent mineralized connective tissue responsible solely for Sharpey fiber insertion, has recently been re-evaluated in light of discoveries implicating cementoblasts in paracrine ligand secretion, particularly members of the Wnt family of glycoproteins. Wnt/β-catenin signaling is a well-established orchestrator of skeletal morphogenesis and bone mass regulation; yet its operation specifically within cementum-derived cellular populations under defined mechanical stimuli has remained systematically undercharacterized. The global burden of periodontal disease—affecting an estimated 1.1 billion individuals with severe periodontitis as of 2025 WHO projections—renders the elucidation of these mechanisms not merely academically significant but clinically urgent. Inadequate mechanobiological models translate directly into suboptimal regenerative outcomes, accelerated orthodontically induced root resorption, and a failure to harness endogenous repair cascades in tissue-engineered periodontal constructs. This investigation therefore undertakes a critical re-evaluation of the tensional homeostasis doctrine by systematically interrogating the extent to which cementoblast-autonomous Wnt3a secretion, elicited under physiologically calibrated cyclic compressive loading, operates as an independent suppressive axis on RANKL-mediated osteoclastogenesis—a regulatory loop entirely unaccounted for in existing FAK-centric mechanotransduction frameworks. The study proceeds as follows: Section 2 details the cell culture, biomechanical loading apparatus, RNA sequencing pipeline, and finite element modeling methodology; Section 3 presents transcriptomic and proteomic data alongside stress-distribution mapping of the alveolar socket; Section 4 critically interprets these findings against prevailing mechanotransduction dogma and discusses translational implications for orthodontic and regenerative periodontal practice; and Section 5 synthesizes conclusions and proposes a revised mechano-endocrine model of cementum function.

References

1. Kravchenko, B. (2026, February). IMPACT OF TOBACCO AND NICOTINE PRODUCTS ON DENTAL IMPLANT OUTCOMES: CLINICAL RISKS AND PREVENTIVE STRATEGIES. In International Science Forum‖(February 6-8, 2026)/Publisher website: www. naukainfo. com.-Oxford, United Kingdom, 2026.-245 p. (p. 190).
2. Kravchenko, B. (2026). Anti-smoking programmes in dentistry: A comparative analysis of approaches in Ukraine and the EU countries. International Journal of Medicine and Medical Research, 12(1), 84-96.
3. Kravchenko, B. I. (2025). Tobacco aggression: modern challenges for dental practice. Oral and General Health, 6(2), 96-96.