Reassessing Osseointegration Kinetics in Titanium Implants: The Underestimated Role of Periimplant Sulcular Microbiota in Early Crestal Bone Remodeling

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Abstract. Osseointegration has long been conceptualized as a predominantly biomechanical phenomenon governed by implant surface topography and host bone density. However, emerging evidence suggests that periimplant sulcular microbiota exert a measurable modulatory influence on crestal alveolar bone remodeling within the critical 0–12 week healing window. This study employed 16S rRNA metagenomic sequencing, micro-computed tomography (micro-CT), and quantitative histomorphometry in a longitudinal cohort of 84 implant-receiving patients to reassess early osseointegration dynamics. Our findings demonstrate that dysbiotic shifts toward Treponema denticola and Prevotella intermedia dominance correlate significantly with accelerated marginal bone loss (MBL) independent of established prosthetic loading parameters. These results challenge the canonical implant success criteria outlined in the Albrektsson threshold model and advocate for sulcular microbiome profiling as a standard perioperative diagnostic protocol.

Keywords: osseointegration, periimplant microbiota, crestal bone remodeling, marginal bone loss, 16S rRNA metagenomics, titanium dental implants, sulcular dysbiosis, micro-computed tomography histomorphometry, Albrektsson threshold model

Introduction

Dental implantology has undergone transformative evolution since Brånemark's foundational characterization of osseointegration in the 1960s, establishing a mechanistic paradigm in which predictable bone-to-implant contact (BIC) is achieved through precise surgical protocol, implant surface engineering, and patient-derived osteogenic capacity. For decades, the dominant clinical and scientific discourse has centered on macro- and micro-scale implant topography — including sandblasted acid-etched (SLA) surfaces, calcium

phosphate coatings, and hydrophilic modifications — as the principal determinants of successful periimplant bone apposition. This reductionist biomechanical framework has underpinned implant success criteria, most notably the Albrektsson and Zarb threshold model, which defines acceptable marginal bone loss (MBL) as not exceeding 1.5 mm during the first year of functional loading, followed by an annual loss of no more than 0.2 mm thereafter. Yet, as the global burden of implant-supported prosthetic rehabilitation expands — with an estimated 15 million implants placed annually worldwide as of 2024 — the incidence of periimplantitis, affecting between 19% and 43% of implant-bearing individuals depending on diagnostic criteria, has exposed a critical explanatory gap in the prevailing osseointegration model. Periimplantitis, defined as a plaque-associated pathological condition resulting in inflammation of the periimplant mucosa and progressive loss of supporting bone, cannot be comprehensively accounted for by biomechanical or surgical variables alone. Epidemiological and microbiological evidence increasingly implicates the composition and metabolic activity of the periimplant sulcular microbiome as an independent and dynamic biological variable operating within the osseointegration continuum from the moment of implant placement. Recent metagenomic investigations have identified a complex, site-specific microbial ecology within periimplant sulci that differs qualitatively and quantitatively from the subgingival microbiome of natural dentition. Keystone pathogens including Treponema denticola, Prevotella intermedia, Fusobacterium nucleatum, and Porphyromonas gingivalis have been detected at significant abundance during the early healing phase, preceding clinical signs of periimplantitis by weeks to months. The inflammatory cytokine cascades triggered by these organisms — particularly the upregulation of interleukin-1β (IL-1β), tumor necrosis factor-α (TNF-α), and receptor activator of nuclear factor kappa-B ligand (RANKL) — are molecularly coherent with osteoclastogenic acceleration and subsequent crestal bone resorption. Despite this mechanistic plausibility, standard perioperative implant protocols in 2024–2026 clinical practice continue to omit structured microbiome profiling, relying instead on generic antimicrobial prophylaxis regimens that do not account for individual sulcular dysbiotic signatures. This article proceeds as follows: Section 2 delineates the materials and methods, encompassing patient recruitment criteria, 16S rRNA metagenomic sequencing workflows, micro-CT acquisition parameters, and histomorphometric analytical protocols. Section 3 presents the quantitative results of correlational analyses between microbial community indices and crestal MBL measurements at 4, 8, and 12 weeks post-implantation. Section 4 provides a critical discussion recontextualizing osseointegration theory within a host-microbiome interactive framework and proposes a revised perioperative diagnostic algorithm. Section 5 concludes with clinical implications and directions for prospective multicenter validation.

References

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