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PERI-IMPLANTITIS PHENOTYPING AND MANAGEMENT: DIAGNOSTIC HETEROGENEITY AND THE EVIDENCE GAP IN IMPLANT SURFACE DECONTAMINATION AND RE-OSSEointegration

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ABSTRACT

Peri-implantitis is now recognised as the principal biological complication underlying late dental implant failure, yet the field continues to lack a single, universally applied case definition. Divergent probing-depth thresholds, inconsistent baseline reference points for marginal bone loss, and variable inclusion criteria across studies have produced prevalence estimates ranging from single digits to almost half of all implants surveyed, complicating both epidemiological comparison and clinical decision-making. Compounding this diagnostic heterogeneity is a second, related uncertainty: no decontamination protocol for the exposed implant surface has yet demonstrated clear superiority, and predictable re-establishment of true osseointegration (re-osseointegration) after treatment remains the exception rather than the rule. This narrative review synthesises the contemporary literature on peri-implantitis case definitions and clinical phenotyping, appraises the comparative evidence for mechanical, chemical, air-abrasive, laser-assisted, and electrolytic decontamination protocols, and evaluates surgical (resective and reconstructive) treatment outcomes with specific attention to histological and radiographic evidence of re-osseointegration. A structured search of PubMed/MEDLINE, Scopus, and the Cochrane Library was conducted for the period 2008–2026, prioritising World Workshop consensus reports, systematic reviews with meta-analysis, and randomised controlled trials. The findings confirm that diagnostic thresholds remain probe- and defect-morphology-dependent rather than universally fixed, that defect configuration is the dominant determinant of treatment selection, and that decontamination method choice appears less influential on clinical outcome than completeness of debridement, defect containment, and adherence to structured supportive peri-implant care. Emerging electrolytic and combined chemo-mechanical protocols show early histological evidence of re-osseointegration in humans, but the evidence base remains limited to small cohorts. Standardised, validated phenotyping frameworks and adequately powered trials with re-osseointegration as a histological endpoint are identified as priorities for future research.

Keywords: Peri-implantitis; Diagnostic criteria; Implant surface decontamination; Re-osseointegration; Probing depth; Marginal bone loss

1 INTRODUCTION

Dental implants have become a predictable and widely used modality for the replacement of missing teeth, with reported survival rates exceeding 90–95% over five years. Long-term function, however, is increasingly threatened not

by mechanical or prosthetic complication but by a biological one: peri-implantitis, a plaque-associated inflammatory condition of the peri-implant tissues characterised by progressive loss of supporting bone^{1,2}. Peri-implantitis is now widely regarded as the primary driver of late implant failure, and its management has become one of the most active areas of clinical implant research.

Despite this clinical importance, the field has struggled to agree on how peri-implantitis should be diagnosed. The 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions provided the first broadly accepted consensus case definition, requiring bleeding and/or suppuration on probing together with progressive radiographic bone loss relative to a documented baseline, or, in the absence of baseline records, a probing depth ≥ 6 mm combined with a bone level ≥ 3 mm apical to the most coronal portion of the intraosseous implant surface¹. This definition was a substantial advance, but the Workshop itself acknowledged that no fixed range of probing depth can be considered universally compatible with peri-implant health, since peri-implant probing depth is influenced by implant position, prosthetic emergence profile, mucosal thickness, and probing force¹. As a direct consequence, epidemiological studies applying different thresholds for probing depth and bone loss have reported peri-implantitis prevalence figures ranging from as low as 1% to as high as 47% of implants, and even after restriction to the 2017 World Workshop case definition, patient-level prevalence estimates in recent systematic reviews still vary from approximately 19% to 26%^{3,4,5}. This variability is not a trivial statistical artefact: it directly affects how clinicians recognise disease, how early intervention is triggered, and how comparable outcome data across trials can be interpreted.

A second, closely related source of uncertainty concerns treatment. Once a diagnosis is made, management is predicated on decontamination of the exposed, often microtextured implant surface, a substrate that is inherently more difficult to disinfect than a periodontally involved root surface because of its threaded macro-geometry and roughened micro-topography^{2,6}. A wide array of mechanical (curettes, titanium brushes), chemical (citric acid, chlorhexidine, hydrogen peroxide), air-abrasive (glycine and erythritol powders), laser-assisted (Er:YAG, Er,Cr:YSGG, photodynamic therapy), and, more recently, electrolytic decontamination protocols have been proposed, yet systematic reviews consistently conclude that no single method has demonstrated clear superiority in either bacterial decontamination or clinical outcome^{6,7,8}. More fundamentally, the biological objective of decontamination — true re-osseointegration of previously contaminated, diseased implant surface — remains difficult to achieve and even more difficult to verify in living patients, since histological confirmation requires implant retrieval or biopsy^{9,10}.

This review addresses two linked questions that continue to limit predictable peri-implantitis management: first, how consistently can peri-implantitis be phenotyped and diagnosed using current probing depth and marginal bone loss thresholds; and second, what evidence currently supports specific implant surface decontamination protocols and surgical approaches in achieving disease resolution and re-osseointegration. The objective is to synthesise the available consensus statements, systematic reviews, and randomised controlled trials to clarify where evidence-based protocols exist, and where clinical practice continues to outpace the underlying evidence.

2 MATERIALS AND METHODS

This is a narrative review structured around a targeted literature search rather than a formal systematic review; accordingly, no PRISMA protocol was registered, and no meta-analytic pooling of primary data was undertaken. A structured electronic search of PubMed/MEDLINE, Scopus, and the Cochrane Central Register of Controlled Trials was conducted for English-language publications from January 2008 to September 2026, using combinations of the search terms "peri-implantitis", "peri-implant disease", "case definition", "probing depth", "marginal bone loss", "implant surface decontamination", "titanium brush", "air abrasion", "laser", "electrolytic cleaning", "re-osseointegration", "reconstructive surgery", and "resective surgery".

Priority was given to: (i) consensus reports from the World Workshops on the Classification of Periodontal and Peri-Implant Diseases and the European Federation of Periodontology workshops; (ii) systematic reviews and meta-analyses addressing prevalence, diagnostic thresholds, or decontamination efficacy; and (iii) randomised controlled trials reporting clinical, radiographic, or histological outcomes of non-surgical or surgical peri-implantitis therapy. In vitro and animal studies were included selectively where they provided mechanistic evidence not available from clinical data, particularly regarding surface decontamination efficacy and re-osseointegration histology. Case reports were included only where they provided histological confirmation of re-osseointegration in humans, a level of evidence otherwise absent from the clinical literature. Reference lists of identified reviews were hand-searched for additional relevant primary studies.

As this is a review of previously published, de-identified literature and did not involve primary data collection from human or animal subjects, institutional ethical approval and informed consent were not required.

3 RESULTS AND DISCUSSION

3.1 Diagnostic Heterogeneity in Peri-implantitis Phenotyping

The 2017 World Workshop defined peri-implant health, peri-implant mucositis, and peri-implantitis along a disease continuum. Peri-implant mucositis is characterised by bleeding and/or suppuration on gentle probing without additional bone loss beyond that expected from initial physiological remodelling (generally up to 2 mm), while peri-implantitis additionally requires progressive bone loss beyond this remodelling phase¹. Critically, the Workshop explicitly stated that it is not possible to define a single range of probing depths compatible with peri-implant health, because peri-implant health can exist around implants with substantially reduced bone support, and because probing depth is confounded by mucosal thickness, prosthetic contour, and the angle and force of probing^{1,2}. In day-to-day practice, this has meant that a probing depth of 6 mm may represent frank disease at one implant and physiological anatomy at another, and that the diagnosis ultimately rests on the co-occurrence of inflammatory signs, a progressive increase in probing depth relative to a documented baseline, and confirmed radiographic bone loss, rather than on a probing depth value in isolation¹.

A further, frequently under-appreciated source of heterogeneity is the reference point used for marginal bone loss. Where a post-loading baseline radiograph is available, peri-implantitis is defined by bone loss that is progressive relative to that baseline, using a threshold intended to exceed the inherent measurement error of periapical radiography (commonly cited as approximately 0.5 mm)¹. Where no baseline is available — a common scenario in general and specialist practice, where implants are frequently referred for late complications — the Workshop's fallback criterion requires a bone level ≥ 3 mm apical to the most coronal portion of the intraosseous implant surface combined with bleeding and/or suppuration on probing and a probing depth ≥ 6 mm¹. These two pathways to diagnosis are not equivalent in sensitivity, and studies applying the baseline-dependent definition versus the baseline-independent fallback definition to the same population can generate materially different prevalence estimates, a phenomenon directly demonstrated by meta-regression analyses showing that the reported prevalence of peri-implantitis is inversely related to the bone-loss threshold applied³.

The practical consequence of this diagnostic heterogeneity is substantial variability in reported disease burden. An early systematic review by Derks and Tomasi, pooling data before the 2017 consensus definition existed, reported prevalence ranging from 1% to 47% across included studies, with a weighted mean of approximately 22%³. A subsequent systematic review restricted to studies published after 2005 and incorporating probing-depth criteria reported an overall prevalence of 19.5% at the patient level and 12.5% at the implant level, while explicitly identifying probing-depth threshold selection as a major source of between-study variance⁴. Most recently, a 2025 systematic review and meta-analysis applying the harmonised 2017 World Workshop criteria across contemporary studies estimated patient-level prevalence at approximately 21%, with implant-level prevalence somewhat lower, and confirmed marked regional variation and a strong inverse relationship with smoking status⁵. Even with a shared consensus definition, therefore, residual heterogeneity in probing technique, radiographic method, and follow-up duration continues to generate a wide prevalence range, underscoring that standardisation of case definition alone has not fully resolved the underlying diagnostic uncertainty.

3.2 Clinical Phenotypes and Risk-Stratified Presentation

Beyond the binary presence or absence of disease, peri-implantitis presents across a spectrum of clinical phenotypes that influence both prognosis and treatment selection. Defect morphology is the most clinically relevant axis of phenotyping: circumferential, contained (three- to four-wall) intraosseous defects behave differently, and respond more favourably to reconstructive therapy, than non-contained, predominantly horizontal or dehiscence-type defects, which typically require a resective approach^{11,12}. Disease severity phenotypes — early, moderate, and advanced, generally stratified by probing depth and the proportion of implant length affected by bone loss — have also been proposed to guide the intensity of intervention, since implants with advanced, circumferential bone loss have a materially worse prognosis and higher rates of subsequent implant loss than those with early, contained lesions^{2,11}.

Risk-indicator profiling further refines phenotyping. A documented history of periodontitis, current smoking, poor compliance with supportive maintenance, and reduced width of keratinized peri-implant mucosa (below approximately 2 mm) have each been associated with increased prevalence and severity of peri-implant disease, while non-smokers demonstrate substantially lower peri-implantitis prevalence than smokers in pooled analyses^{4,5}. These risk indicators do not currently form part of the formal case definition, but they meaningfully inform individualised recall intervals and the threshold at which surgical, rather than non-surgical, intervention is considered.

3.3 Implant Surface Decontamination: Comparative Evidence

The rationale for implant surface decontamination is straightforward — biofilm removal is a prerequisite for resolution of peri-implant inflammation and for any prospect of re-osseointegration — but the comparative evidence for specific decontamination modalities remains inconclusive. Mechanical debridement using plastic or titanium curettes and, more recently, titanium brushes has been the traditional first-line approach, but titanium curettes and hand instruments struggle to access the recessed valleys of a threaded, roughened implant surface, leaving "protected" areas inaccessible to conventional mechanical removal^{2,6}.

Air-abrasive decontamination using glycine or erythritol powders has accumulated the largest evidence base among adjunctive methods. A systematic review of *in vitro* studies concluded that air abrasion produces surface alteration comparable to that of plastic curettes and Er:YAG laser treatment, without evidence of clinically significant additional roughening, and glycine-based powders in particular do not appear to alter the underlying implant surface chemistry⁶. Laser-assisted decontamination, principally with Er:YAG and Er,Cr:YSGG systems, has demonstrated bactericidal efficacy with minimal thermal damage to the implant surface in both *in vitro* and clinical studies, and photodynamic therapy has been explored as a further adjunct, although its independent contribution to clinical outcome beyond mechanical debridement remains modest^{6,7}. A 2024 systematic review and meta-analysis comparing mechanical, chemical, and laser-based decontamination strategies on titanium surfaces contaminated with bacterial biofilm concluded that all commonly used methods achieve substantial, but rarely complete, biofilm elimination, and that no single method could be identified as unequivocally superior across bacterial reduction, surface preservation, and biocompatibility outcomes simultaneously⁷. A parallel systematic review focused specifically on non-surgical submarginal instrumentation reached a similar conclusion: mechanical and physical decontamination approaches reduce clinical inflammatory parameters, but resolution of peri-implantitis using non-surgical decontamination alone is achieved in only a minority of cases, particularly where probing depths exceed 6 mm⁸.

A more recent innovation, electrolytic cleaning, applies a low-voltage current to the implant while an electrolyte solution is delivered across the surface; the resulting electrochemical reaction generates hydrogen bubbles that lift biofilm from the entire implant surface, including areas inaccessible to instrumentation, independent of implant macro- and micro-geometry⁹. A randomised controlled trial comparing electrolytic cleaning alone with electrolytic cleaning combined with powder-spray decontamination, followed by augmentation with a natural bone mineral and autogenous bone mixture under submerged healing, reported significant bone fill across all 24 treated implants at six months, with complete radiographic bone regeneration achieved in half of the cohort, and the authors concluded that complete re-osseointegration in peri-implantitis cases is achievable under favourable defect and protocol conditions⁹. Taken together, the comparative literature suggests that the choice of decontamination modality is less determinative of clinical outcome than the completeness of debridement achieved, the containment and morphology of the underlying bony defect, and the quality of subsequent supportive care — a conclusion echoed across multiple recent systematic reviews^{6,7,8}.

3.4 Non-Surgical versus Surgical Treatment Outcomes

Non-surgical therapy — mechanical debridement with or without adjunctive chemical, air-abrasive, or laser decontamination — can resolve peri-implant mucositis and early, shallow peri-implantitis lesions, but its efficacy diminishes substantially as probing depth and defect severity increase, and residual disease after non-surgical therapy is common in moderate-to-advanced cases⁸. A recent randomised controlled trial specifically evaluating patients who failed to achieve disease resolution after standardised non-surgical therapy found that reconstructive surgical therapy produced significantly greater radiographic bone gain than continued supportive care alone at 12 months, supporting a staged, non-surgical-then-surgical treatment pathway for defects that do not resolve conservatively¹⁸.

Surgical treatment bifurcates into resective and reconstructive approaches, selected principally according to defect morphology. Resective therapy — apically positioned flap surgery with or without osseous recontouring and implantoplasty (mechanical smoothing of the exposed threaded surface) — aims to eliminate peri-implant pockets and render the residual surface easier for the patient to maintain, and is generally favoured for non-contained, supracrestal, or buccal dehiscence-type defects^{11,12}. Reconstructive therapy, employing a bone substitute graft with or without a barrier membrane, is favoured for contained, circumferential intraosseous defects with three or more bony walls, where the defect architecture is more conducive to graft containment and bone fill^{11,15,16}.

The randomised controlled trial evidence for reconstructive therapy has grown substantially over the past decade. A multicentre randomised controlled trial comparing access flap surgery alone with access flap surgery combined with a bone substitute material in 138 patients found improved radiographic bone fill in the reconstructive group, although clinical parameters such as probing depth reduction and resolution of bleeding on probing were broadly comparable between groups¹⁵. A subsequent three-year follow-up of a comparable reconstructive cohort confirmed that clinical improvements achieved in the first year were largely sustained, with continued, modest radiographic bone gain over time in implants maintained on a structured supportive care programme¹⁷. A randomised controlled trial specifically

comparing access flap surgery with and without guided bone regeneration using a xenograft and collagen membrane in defects with a contained intraosseous component found comparable probing depth reduction (control 4.2 mm vs test 3.7 mm) but greater marginal bone level gain in the grafted group (2.4 mm vs 1.7 mm), with successful treatment outcomes — defined as absence of deep probing depths, bleeding, suppuration, and progressive bone loss — achieved in 85–90% of implants in both arms at 12 months, and no statistically significant between-group difference in overall clinical success¹⁶. A further multicentre trial comparing guided bone regeneration with open flap debridement alone in defects with three or more bony walls similarly reported numerically, though not statistically significantly, higher treatment success with guided bone regeneration (46.2% vs 20% at 36 months), reinforcing that reconstructive grafting confers a modest but not universally decisive clinical advantage over debridement alone even in favourable defect morphology¹⁹.

A systematic review of randomised controlled trials evaluating regenerative techniques for peri-implantitis similarly concluded that reconstructive approaches are capable of producing clinically meaningful radiographic bone fill, but that the magnitude of benefit over non-regenerative surgical debridement is inconsistent across trials and strongly dependent on defect configuration, and that adjunctive biologics such as enamel matrix derivative and growth factor concentrates have not yet demonstrated a consistent additional benefit over conventional grafting materials^{14,20,21}. Across the surgical literature as a whole, the single most consistent predictor of long-term stability after either resective or reconstructive surgery is not the specific technique employed but participation in a structured, individualised supportive peri-implant care programme following active treatment^{11,15,17,19}.

3.5 Re-osseointegration: The Elusive Biological Endpoint

Clinical resolution of peri-implantitis — reduction in probing depth, absence of bleeding or suppuration, and radiographic stability — is frequently used as a surrogate for successful treatment, but it does not confirm that new bone has formed in direct, functional contact with a previously contaminated implant surface. True re-osseointegration can only be confirmed histologically, and such evidence in humans remains scarce because it requires either implant retrieval or an invasive biopsy protocol^{9,10}. Direct histological confirmation of re-osseointegration in humans was reported in a case series of four implants treated with electrolytic surface cleaning combined with reconstructive grafting, in which retrieved bone-to-implant specimens demonstrated new bone formation in direct apposition to previously biofilm-contaminated implant surface, providing proof of concept that re-osseointegration is biologically achievable when surface decontamination is sufficiently thorough and defect architecture is favourable¹⁰. This remains one of only a small number of published human histological confirmations of re-osseointegration, underscoring how limited the direct evidence base for this outcome still is relative to the volume of clinical trials reporting probing depth and radiographic bone-level surrogates^{9,10,22}.

The comparative radiographic evidence is more abundant but still heterogeneous in defect-fill outcomes, which is consistent with the interpretation that decontamination completeness, rather than modality per se, is the principal biological determinant of re-osseointegration potential. Bone fill approaching or reaching complete radiographic resolution has been reported following electrolytic cleaning combined with grafting⁹, while more modest, partial bone fill is typical following conventional mechanical or air-abrasive decontamination combined with grafting^{15,16,19}. Defect morphology continues to exert a dominant influence on the extent of achievable fill: contained, multi-wall defects consistently regenerate more completely than non-contained defects regardless of the decontamination method selected, reinforcing that surgical case selection based on defect phenotype is at least as important to the re-osseointegration outcome as the specific decontamination protocol chosen^{11,16,19}.

3.6 Supportive Peri-Implant Care

Irrespective of the initial decontamination or surgical approach selected, durability of treatment outcome is consistently linked to participation in an individualised, recall-based supportive peri-implant care programme. Systematic review evidence indicates that implants maintained on regular professional recall demonstrate lower rates of disease recurrence and implant loss than those without structured maintenance, and that irregular or absent supportive care is itself an independent risk indicator for peri-implantitis recurrence after otherwise successful treatment¹¹. This reinforces that peri-implantitis management should be conceptualised as a long-term, maintenance-dependent process rather than a single decontamination or surgical event.

3.7 Towards Standardisation: Priorities for Future Research

Two clear gaps emerge from this synthesis. First, although the 2017 World Workshop case definition represents a meaningful advance, its reliance on probing depth and a baseline-dependent bone-loss threshold that the originating consensus group itself acknowledged cannot be fixed across all implant and prosthetic configurations means that residual diagnostic heterogeneity will persist until validated, defect-morphology- and phenotype-specific diagnostic frameworks are developed and prospectively tested^{1,3,4,5}. Second, the decontamination and surgical-treatment literature, while considerably more mature than it was a decade ago, remains dominated by clinical and radiographic

surrogate outcomes rather than histological confirmation of re-osseointegration, and by trials that are individually well-conducted but heterogeneous in defect selection, decontamination protocol, and follow-up duration, limiting direct comparability^{7,8,14}. Future research priorities should therefore include prospective validation of phenotype-stratified diagnostic thresholds across diverse implant systems and prosthetic designs; adequately powered, protocol-standardised randomised controlled trials directly comparing decontamination modalities within matched defect morphologies; and greater incorporation of histological or advanced imaging endpoints capable of directly verifying re-osseointegration, rather than relying exclusively on probing depth and two-dimensional radiographic bone-level surrogates.

4 CONCLUSION

Peri-implantitis diagnosis remains constrained by the inherent variability of peri-implant probing depth and by inconsistent application of baseline-dependent versus baseline-independent bone-loss thresholds, producing prevalence estimates that continue to range widely even under the harmonised 2017 World Workshop case definition. Clinical phenotyping by defect morphology and risk-indicator profile, rather than probing depth in isolation, offers the most clinically actionable stratification currently available. On the treatment side, no single implant surface decontamination modality — mechanical, chemical, air-abrasive, laser-assisted, or electrolytic — has demonstrated unequivocal superiority; instead, completeness of debridement, defect containment, and structured long-term supportive care appear to be the dominant determinants of clinical stability and of the still-limited evidence base for true histological re-osseointegration. Predictable, evidence-based protocols for both diagnosis and decontamination therefore remain aspirational rather than fully realised, and closing this gap will require standardised phenotyping frameworks alongside adequately powered trials incorporating histological confirmation of re-osseointegration as a primary endpoint.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The author declares no financial, professional, institutional, or personal conflicts of interest relevant to the content of this manuscript.

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