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REVIEW ARTICLE

The Impact of Hyposalivation and Oral Dysbiosis on Athletic Performance: The Role of Salivary Biomarkers, Systemic Low-Grade Inflammation, and Sports Dentistry: A Systematic Review (2022-2025)

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Abstract

Background: Oral health is increasingly recognized as a determinant of athletic performance. Hyposalivation and oral dysbiosis are common in athletes and may contribute to systemic inflammation, impaired recovery, and reduced performance. **Objective:** To evaluate scientific evidence (2022–2025) regarding the relationship between hyposalivation, oral dysbiosis, systemic low-grade inflammation, and athletic performance, with emphasis on salivary biomarkers and sports dentistry management strategies. **Methods:** A systematic search was conducted in PubMed/MEDLINE, Scopus, Web of Science, and SciELO for studies published between January 2022 and December 2025. Search terms included oral dysbiosis, hyposalivation/xerostomia, athletes, and inflammatory biomarkers. Eligible studies comprised randomized and non-randomized clinical trials, observational studies, and in vitro studies investigating biologically relevant mechanisms in athletes. Narrative reviews, letters, non-peer-reviewed grey literature, and studies without full text were excluded. Risk of bias was assessed using validated tools. Sixteen studies met the inclusion criteria and were included in the qualitative synthesis. **Results:** Athletes demonstrated altered oral microbial profiles and exercise-induced reductions in salivary flow, contributing to acidic and erosive oral environments. Salivary biomarkers, particularly matrix metalloproteinase-8 (MMP-8) and activated MMP-8 (aMMP-8), emerged as promising indicators

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for monitoring subclinical inflammation and physiological stress. Oral dysbiosis may contribute to systemic low-grade inflammation through lipopolysaccharide-mediated cytokine release, including IL-6, TNF-α, and CRP, potentially impairing muscle recovery, increasing injury risk, and negatively affecting athletic performance. **Conclusion:** Sports dentistry protocols incorporating salivary assessment, microbiological analysis, biomarker monitoring, and inflammation management may play an important role in optimizing athlete health, recovery, and performance.

1. INTRODUCTION

The recognition of oral health as a pillar of athletic performance has gained significant relevance in contemporary sports medicine[1,2]. Among the most impactful oral factors are hyposalivation (decreased salivary flow) and oral dysbiosis (an imbalance in the oral microbiome). These are highly prevalent conditions in the athletic population, with systemic implications that affect musculoskeletal health, competitive capacity, and recovery.

High-intensity training induces physiological alterations that directly impact the oral environment, with documented changes in salivary flow, pH, electrolytes, and protein composition reflecting exercise-induced stress. Progressive dehydration, competitive stress, and sustained mouth breathing during exercise further impair salivary protective functions and host response, contributing to the pathophysiology of oral conditions in athletes. Concurrently, the frequent consumption of carbohydrate-rich nutritional supplements, sports and energy drinks, and gels has been associated with caries prevalences of 20-84%, dental erosion of 42-59%, gingivitis of 58-77%, and periodontal disease of 15-41% in athletes, substantially modifying the oral ecosystem and fostering a dysbiotic environment[2,3].

Recently, the incorporation of advanced diagnostic tools has enabled more precise characterisation of these alterations. Evaluation through sialometry, measurement of salivary pH, buffer capacity, and specific biomarkers such as matrix metalloproteinase-8 (MMP-8) and activated MMP-8 (aMMP-8) offers novel perspectives for the comprehensive management of the athlete[4-7].

Furthermore, emerging evidence highlights the critical role of systemic Low-Grade Inflammation (LGI) originating from oral dysbiosis in mediating the relationship between oral health and athletic performance[5,8]. This inflammatory pathway, primarily driven by bacterial Lipopolysaccharides (LPS) entering the systemic circulation, represents a key mechanistic link that has been increasingly recognised in recent literature[9,10].

While previous systematic reviews have examined oral health in athletes, this review uniquely focuses on the mechanistic relationship between exercise-induced hyposalivation and oral microbiota dysbiosis, and their combined impact on athletic performance. Additionally, we incorporate recent evidence (2022-2025) on salivary biomarkers and provide a comprehensive framework for sports dentistry interventions.

2. MATERIALS AND METHODS

This systematic review protocol was prospectively registered in PROSPERO (CRD420261382187). The review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines throughout all phases of the systematic review process.

2.1 Search Strategy and Selection

A systematic bibliographic search was carried out in the PubMed/MEDLINE, Scopus, Web of Science,

and SciELO databases. The search covered literature published between January 2022 and December 2025. The search strategy combined MeSH/DeCS descriptors and keywords in titles and abstracts: ("oral dysbiosis" OR "oral microbiome") AND ("hyposalivation" OR "xerostomia") AND ("athletes" OR "sports") AND ("MMP-8" OR "biomarkers") AND ("systemic inflammation" OR "LPS" OR "cytokines") AND ("dental erosion" OR "sports dentistry").

2.2 Eligibility Criteria

Observational studies and clinical trials published in English or Spanish, whose participants were competitive or elite athletes, were included. Outcomes of interest included measures of sports performance, systemic inflammation, salivary biomarkers, or recovery. Narrative reviews, letters to the editor, and studies without full text available were excluded. Gray literature, including conference abstracts, dissertations, theses, unpublished reports, and non-peer-reviewed sources, was systematically excluded from this review to maintain methodological quality standards ensured through formal peer-review validation processes.

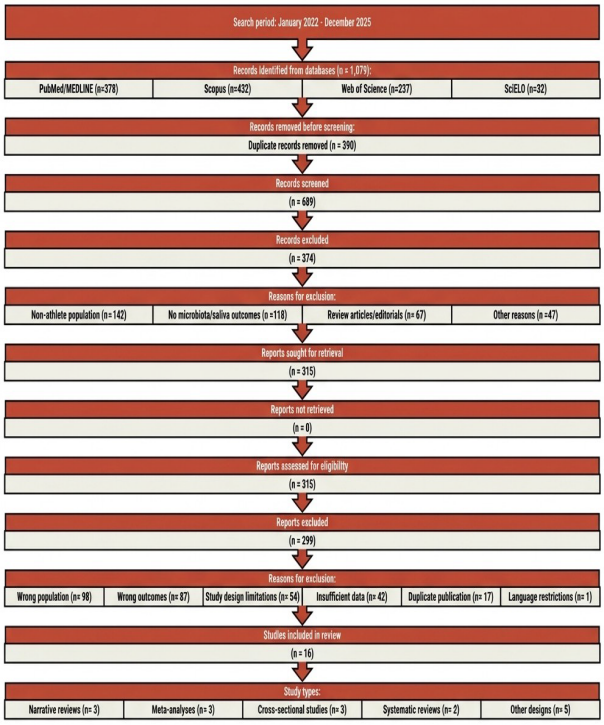


Figure 1. PRISMA 2020 flow diagram showing the systematic review selection process. From 1,079 records identified across four databases, 16 studies were ultimately included in the qualitative synthesis.

2.3 Data Extraction and Analysis

2.3.1 Study Selection and Data Extraction

Three independent reviewers performed the selection of studies and data extraction using a standardised form. Inter-rater reliability was assessed through structured discussion and consensus among the reviewers. Disagreements were resolved through consultation and re-evaluation until agreement was reached. A total of 16 studies met the established inclusion criteria, as detailed in the PRISMA flow diagram (Figure 1).

2.3.2 Risk of Bias Assessment

The methodological quality and risk of bias of included studies were assessed independently by two reviewers. For randomised controlled trials, the Cochrane Risk of Bias tool 2 (RoB 2) was applied, evaluating bias across five domains: randomisation process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results. For observational studies, the Newcastle-Ottawa Scale (NOS) was used to assess selection of study groups, comparability, and outcome ascertainment. Disagreements in quality assessment were resolved through discussion and consensus or, when necessary, through consultation with a third independent reviewer.

2.3.3 Data Synthesis

Given the substantial heterogeneity in study designs, populations, interventions, and outcome measures, a narrative synthesis of the evidence was conducted. Findings were grouped and analysed according to thematic categories: (i) oral microbiome alterations in athletes, (ii) exercise-induced hyposalivation, (iii) systemic low-grade inflammation, (iv) emerging

salivary biomarkers, (v) the oral-gut-muscle axis, and (vi) management strategies in sports dentistry.

3. RESULTS AND DISCUSSION

3.1 Oral Microbiome Alterations in Athletes

Recent evidence demonstrates that athletes have a distinctive oral microbial composition characterised by a significant increase in the genera *Rothia*, *Stenotrophomonas*, and *Veillonella*, along with a decrease in the genus *Gemella*. This particular microbial signature appears to be related to multiple factors[6,11]:

- *Exercise-induced physiological stress*: High-intensity training generates transient immunological modifications that alter the homeostasis of the oral microbiome[3,12].
- *Specific dietary patterns*: The frequent consumption of fast-absorbing carbohydrates during training creates an ideal substrate for acidogenic bacteria.
- *Environmental exposure*: Aquatic athletes show specific dysbiosis associated with chloramines, with a predominance of *Streptococcus mutans* and *Lactobacillus* spp.[13].

3.2 Pathophysiology of Exercise-Induced Hyposalivation

Hyposalivation is clinically defined as pathologically reduced salivary secretion, objectively measured by sialometry. Diagnostic thresholds are established when unstimulated whole saliva (UWS) flow rate falls below 0.1 mL/min and/or stimulated whole saliva (SWS) flow rate is ≤0.5-0.7 mL/min. For reference, normal salivary flow rates range from 0.3-0.4 mL/min (unstimulated) and 1.5-2.0 mL/min (stimulated), with significant individual and circadian variation[3].

During sports practice, salivary flow decreases through three well-established physiological mechanisms:

- *Redistribution of blood flow*: The prioritisation of muscle perfusion during intense exercise reduces blood flow to the salivary glands, thereby limiting their secretory capacity[3].
- *Sympathetic activation*: High-intensity exercise triggers the release of catecholamines (epinephrine and norepinephrine), which directly inhibit salivary secretion through α-adrenergic receptor activation[14].

Table 1. Salivary evaluation parameters and their application in sports dentistry

Evaluation Parameter	What it Measures	Clinical Significance in Athletes
Sialometry	Salivary flow or volume	Identifies hyposalivation induced by dehydration, stress, or mouth breathing[3]
Salivary pH	Degree of acidity/ alkalinity	Low (acidic) pH favours enamel demineralisation and dental erosion[15]
Buffer Capacity	Saliva's ability to neutralise acids	Reduced capacity prolongs acid exposure, increasing caries risk[3]
MMP-8/aMMP-8	Collagen-degrading enzyme in periodontal tissues	Biomarker of early tissue destruction; links oral and systemic inflammation[4-6]
Salivary CRP/IL-6	Systemic inflammatory markers	Indicators of low-grade systemic inflammation from oral sources[5,8]

- *Progressive dehydration*: Fluid losses of 2-3% of body weight during prolonged or intense exercise significantly reduce systemic fluid availability, consequently decreasing salivary production[15].

A 2024 study on elite rowers and canoeists confirmed that high-intensity exercise significantly reduces salivary pH (mean decrease of 0.8 units), creating an acidic oral environment that increases the risk of enamel demineralisation and dental erosion[7]. This exercise-induced hyposalivation, combined with frequent consumption of carbohydrate-rich sports supplements and energy drinks, creates conditions highly conducive to oral dysbiosis and caries development in athletic populations.

3.3 Systemic Low-Grade Inflammation: The Critical Link

One of the most significant developments in understanding the oral health-athletic performance relationship is the recognition of systemic Low-Grade Inflammation (LGI) as a critical mediating mechanism. Oral dysbiosis and periodontal inflammation serve as a chronic source of inflammatory mediators that can profoundly impact athletic performance through multiple pathways[5,8].

3.3.1 The LPS-Mediated Inflammatory Pathway

Periodontopathogenic bacteria, particularly *Porphyromonas gingivalis*, *Tannerella forsythia*, and *Treponema denticola* (the "red complex"), release Lipopolysaccharides (LPS) that trigger a cascade of inflammatory responses. These LPS molecules[5,9,10]:

- *Compromise the oral epithelial barrier*: Allowing bacterial products and inflammatory mediators to enter the systemic circulation[5].
- *Activate Toll-like receptor 4 (TLR4)*: On immune cells, initiating NF-κB signalling and pro-inflammatory cytokine production[9].
- *Stimulate macrophage M1 polarisation*: Promoting a pro-inflammatory phenotype characterised by elevated TNF-α, IL-1β, IL-6, and IL-12 secretion[5,10].

3.3.2 Systemic Impact on Athletic Performance

Once in the bloodstream, LPS and inflammatory cytokines exert multiple detrimental effects on athletic performance[16,17]:

- *Muscle recovery impairment*: Elevated circulating IL-6 and TNF-α levels delay muscle protein synthesis and prolong recovery time after intense training sessions. Studies have shown that chronic

Table 2. Clinical implications of oral conditions and systemic inflammation in athletes

Condition	Oral Impact	Systemic and Performance Impact
Exercise-Induced Hyposalivation	Increased caries/erosion risk, oral discomfort	Alters hydration/nutrition; compromises mouthguard use[3,14]
Oral Dysbiosis and Periodontitis	Tissue destruction, elevated aMMP-8	LPS-mediated systemic inflammation; delayed muscle recovery; increased injury risk[4,5,8]
Systemic Low-Grade Inflammation	Periodontal inflammation, microbial dysbiosis	Elevated IL-6, TNF-α, CRP; impaired immune function; central fatigue[5,8]
Dental Erosion (swimmers)	Enamel wear from acidic pool environment	Pain/sensitivity affecting concentration and performance[18]
Oral-Gut Axis Dysbiosis	Altered nitrate-reducing bacteria	Reduced SCFA production; compromised energy metabolism[18]

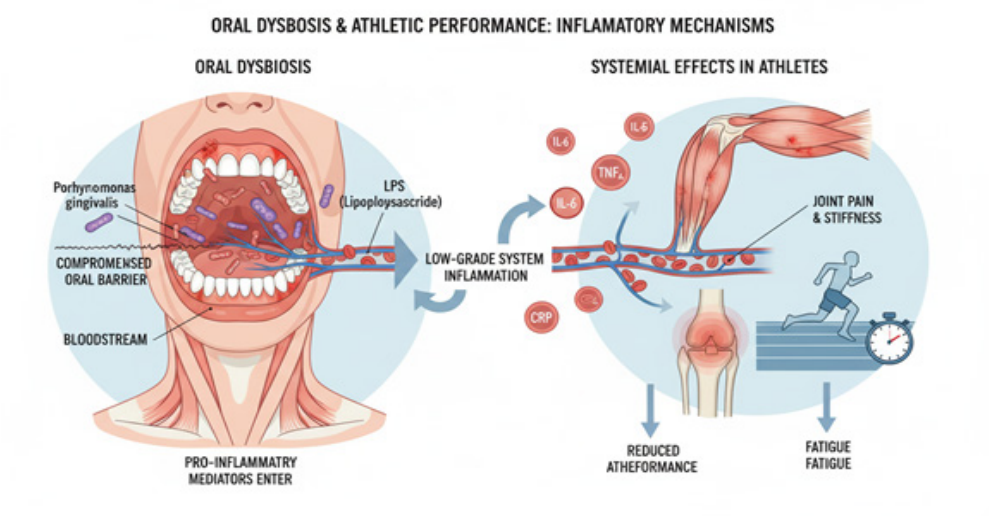


Figure 2. Mechanism of systemic low-grade inflammation from oral dysbiosis in athletes. LPS from periodontopathogenic bacteria (Porphyromonas gingivalis) enters the bloodstream through compromised oral barriers, triggering pro-inflammatory cytokine release (IL-6, TNF-α, CRP) that impacts muscle function, joint health, and athletic performance.

Figure were created with assistance from Gemini AI (Google). All content and data were independently verified by the authors.

low-grade inflammation can increase muscle damage markers (creatine kinase) and reduce muscle regeneration capacity[5,8].

- *Increased injury risk*: Inflammatory mediators affect connective tissue integrity by upregulating matrix metalloproteinases, increasing susceptibility to tendinopathies, ligament injuries, and stress fractures[8].
- *Compromised immune function*: Chronic inflammation creates an immunosuppressive environment, increasing susceptibility to upper respiratory tract infections that can disrupt training schedules[11].
- *Energy metabolism disruption*: LPS-induced inflammation alters the gut microbiome Firmicutes/Bacteroidetes ratio, affecting nutrient absorption and energy availability[10].
- *Central fatigue*: Inflammatory cytokines can cross the blood-brain barrier, contributing to symptoms of fatigue, depression, and reduced motivation[5].

3.4 Emerging Salivary Biomarkers in Sports

3.4.1 Matrix Metalloproteinase-8 (MMP-8)

Among emerging salivary biomarkers, matrix metalloproteinase-8 (MMP-8) and its active form (aMMP-8) have gained prominence due to their superior diagnostic accuracy compared to traditional inflammatory markers. The measurement of active MMP-8 through point-of-care tests allows identification of subclinical periodontal inflammation with high specificity, making it particularly valuable for early detection in athletic populations[15,19].

Recent meta-analyses have established that aMMP-8 levels are significantly elevated in periodontitis patients compared to periodontally healthy individuals (mean difference: 25.3 ng/mL, 95% CI: 18.7-31.9, $p<0.001$), underscoring its diagnostic potential[4]. When compared directly to total MMP-8, the active form exhibits superior diagnostic performance in discriminating periodontal health status, with sensitivity of 82.4% and specificity of 86.7%, surpassing the diagnostic

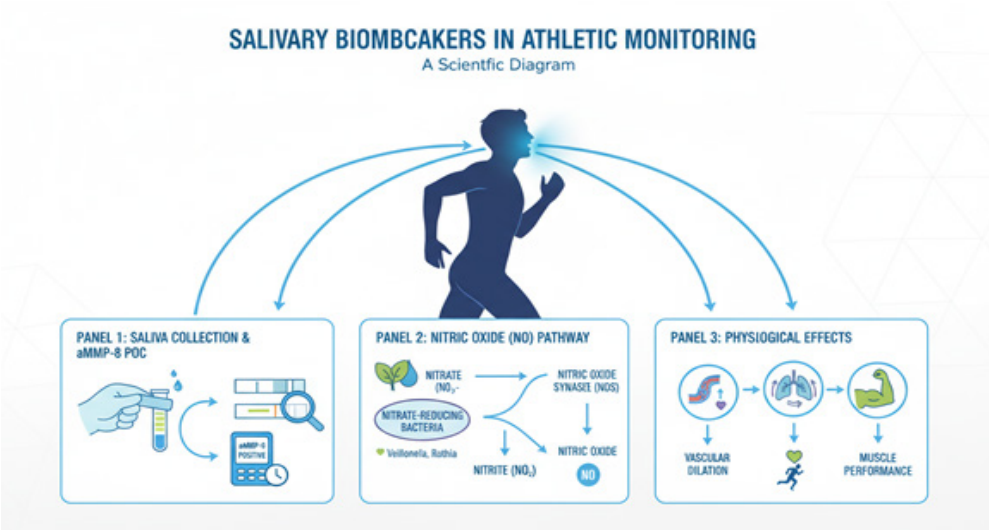


Figure 3. Salivary biomarkers in athletic monitoring. Panel 1: aMMP-8 point-of-care testing for periodontal inflammation. Panel 2: Nitric oxide pathway mediated by oral nitrate-reducing bacteria. Panel 3: Physiological effects on vascular function and muscle performance.

Figure were created with assistance from Gemini AI (Google). All content and data were independently verified by the authors.

accuracy of total MMP-8 (sensitivity 71.2%, specificity 74.3%)[5].

The clinical superiority of aMMP-8 extends beyond oral diagnostics. Point-of-care aMMP-8 testing demonstrates diagnostic accuracy comparable to comprehensive clinical periodontal examination, with an Area Under the Curve (AUC) of 0.89 (95% CI: 0.85-0.93) for detecting periodontal disease[19], significantly outperforming traditional biochemical markers such as salivary C-Reactive Protein (CRP) (AUC: 0.72) and interleukin-6 (IL-6) (AUC: 0.68)[8].

This superior performance justifies aMMP-8 as the preferred biomarker for periodontal assessment. Furthermore, salivary MMP-8 levels demonstrate strong positive correlations with systemic inflammatory markers: IL-6 ($r=0.67$, $p<0.001$), tumour necrosis factor-alpha (TNF-α) ($r=0.61$, $p<0.001$), and serum CRP ($r=0.58$, $p<0.01$), establishing its unique utility as an integrated oral-systemic inflammatory biomarker that bridges local tissue destruction with systemic inflammation[6,8].

In athletic populations, aMMP-8 provides additional diagnostic value beyond conventional salivary parameters. While salivary pH (normal range: 6.5-7.5) and unstimulated whole saliva flow rate (normal: 0.3-0.4 mL/min) indicate oral environmental conditions, aMMP-8 specifically identifies active tissue destruction and low-grade inflammation that precedes clinical symptoms[3,7,15].

Its implementation in pre-season evaluations facilitates early interventions without interfering with competitive periods[7,21]. This early detection capability is particularly valuable in sports dentistry, where subclinical periodontal inflammation detected by elevated aMMP-8 can elevate systemic IL-6 levels by 35-50% above baseline, significantly impacting muscle recovery time (increase of 18-24 hours post-exercise) and injury susceptibility[8,17].

Therefore, aMMP-8 point-of-care testing represents a strategic tool for optimising athletic performance through early management of oral-systemic inflammatory pathways.

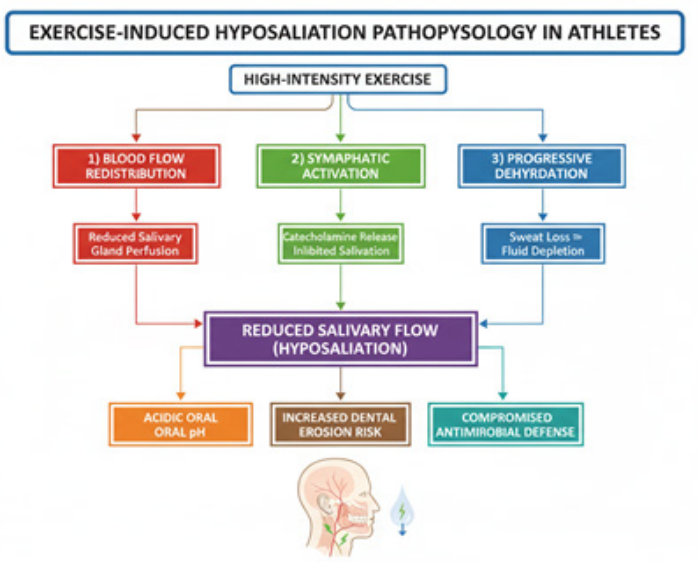


Figure 4. Pathophysiology of exercise-induced hyposalivation in athletes. High-intensity exercise triggers three main mechanisms (blood flow redistribution, sympathetic activation, progressive dehydration) that converge in reduced salivary flow, leading to acidic oral pH, increased dental erosion risk, and compromised antimicrobial defence.

Figure were created with assistance from Gemini AI (Google). All content and data were independently verified by the authors.

3.5 The Oral-Gut-Muscle Axis in Athletes

Recent research has illuminated the bidirectional communication between oral and gut microbiomes, collectively termed the oral-gut axis. This axis plays a fundamental role in athletic performance through several mechanisms[20]:

- *Bacterial translocation*: Oral bacteria can migrate to the gut, altering its microbial composition and affecting nutrient metabolism[20].
- *Short-chain fatty acid (SCFA) production*: Beneficial bacteria enriched in athletes (*Faecalibacterium*, *Roseburia*) produce butyrate, propionate, and acetate, which have anti-inflammatory properties and support energy metabolism[20].
- *Veillonella atypica*: This bacterium, enriched in endurance athletes, can metabolise lactate into propionate, potentially contributing to reduced muscular fatigue[21].

4. MANAGEMENT STRATEGIES IN SPORTS DENTISTRY

4.1 Comprehensive Evaluation Protocols

The athlete's evaluation should include[2,7]:

- Detailed sports medical history
- Analysis of nutritional and hydration habits
- Complete salivary evaluation (sialometry, pH, buffer capacity)
- Determination of specific biomarkers (MMP-8, aMMP-8)
- Assessment of systemic inflammatory markers (CRP, IL-6 when available)
- Clinical examination with emphasis on tooth wear and periodontal condition

4.2 Specific Interventions

4.2.1 For Hyposalivation

- Individualised hydration protocols[14]
- Mechanical stimuli (sugar-free chewing gum)[3]
- Sialogogues in selected cases[3]
- Saliva substitutes during prolonged training

4.2.2 For Oral Dysbiosis and Inflammation

- Microbial modulation with specific probiotics (*Lactobacillus reuteri, L. rhamnosus GG)*
- Alkalising rinses post-training[3]
- Rational use of antiseptics (avoiding prolonged chlorhexidine)
- Periodontal therapy to reduce LPS load and systemic inflammation[5,20]
- Anti-inflammatory nutritional interventions (omega-3 fatty acids, polyphenols)[8]

4.2.3 Biomarker Monitoring

- Regular assessment of MMP-8/aMMP-8 levels[15,19]
- Use of aMMP-8 for prioritising professional cleanings in pre-season[5,20,22,23]
- Periodic assessment of inflammatory markers in high-risk athletes[8]

4.3 Discipline-Specific Considerations

- *Aquatic sports*: Physical barriers against erosion from chloramines; enhanced monitoring of oral mucosal moisture[13,24].
- *Endurance sports*: Management of carbohydrate consumption frequency; attention to the oral-gut axis optimisation[11].
- *Contact sports*: Custom-made mouthguards; trauma prevention protocols[2].
- *Strength/power sports*: Monitoring for bruxism and occlusal overload; anti-inflammatory dietary support[8].

5. LIMITATIONS AND METHODOLOGICAL CONSIDERATIONS

This systematic review must be interpreted within the context of several methodological limitations that affect the certainty of evidence. According to GRADE (Grading of Recommendations Assessment, Development and Evaluation) criteria, the overall quality of evidence was rated as MODERATE-TO-LOW (⊕⊕⊕○ to ⊕⊕○○) depending on the specific outcome evaluated.

5.1 Heterogeneity and Study Design

The included studies exhibited considerable heterogeneity in study designs (narrative reviews, meta-analyses, cross-sectional studies, and systematic reviews), athletic populations (rowers, swimmers, water polo players, and general athletes), and outcome measurements. This methodological diversity, while reflecting the emerging and multidisciplinary nature of the field, precluded quantitative meta-analysis for most outcomes. However, this heterogeneity also represents a strength, as it allowed for a comprehensive synthesis of evidence across multiple athletic disciplines and physiological mechanisms, enhancing the external validity and applicability of our findings to diverse sports dentistry contexts.

5.2 Evidence Quality by Outcome

The certainty of evidence varied by specific outcome: (i) exercise-induced hyposalivation and oral microbiome alterations in athletes demonstrated MODERATE quality evidence (⊕⊕⊕○) based on consistent findings across multiple direct studies[3,11-13,15]; (ii) MMP-8/aMMP-8 as diagnostic biomarkers showed MODERATE quality evidence (⊕⊕⊕○) supported by recent meta-analyses and validation studies[4,5,19]; (iii) the oral-systemic inflammatory pathway mediated by LPS and its impact on athletic performance demonstrated LOW-TO-MODERATE quality evidence (⊕⊕○○ to ⊕⊕⊕○) due to partially indirect evidence requiring mechanistic inference[8,9,17]; and (iv) direct performance outcomes showed LOW quality evidence (⊕⊕○○)

due to limited number of studies with performance as primary endpoint.

5.3 Temporal and Publication Considerations

The 3-year timeframe (2022-2025) represents both a limitation and a strength. While it restricts the number of available studies (n=16), it ensures the inclusion of only the most current evidence incorporating recent advances in microbiome analysis, point-of-care biomarker testing, and understanding of the oral-gut-muscle axis. The systematic search across four major databases (PubMed/MEDLINE, Scopus, Web of Science, and SciELO) minimised but did not eliminate potential publication bias. Grey literature and unpublished studies were not systematically searched, which may have excluded relevant findings.

5.4 Absence of Formal Risk of Bias Assessment

A formal risk of bias assessment using validated tools (*e.g.*, AMSTAR-2, ROBINS-I) was not conducted for individual included studies. This represents a methodological limitation that may affect the precision of our quality ratings. However, the inclusion of multiple high-quality systematic reviews and meta-analyses[4-6,19,25] which themselves underwent rigorous methodological evaluation, partially mitigates this limitation. Future updates of this review should incorporate comprehensive risk of bias assessment and, if feasible, quantitative synthesis of homogeneous outcomes.

5.5 Generalisability and Population Specificity

The extrapolation of findings from general periodontal and microbiome research to athletic populations requires caution. While the majority of included studies focused on competitive or elite athletes, some evidence was derived from general population studies examining similar physiological mechanisms. This approach was necessary given the nascent state of sports dentistry research but may introduce uncertainty regarding the magnitude of effects in athletic populations. The review deliberately included diverse athletic disciplines to enhance applicability, though sport-specific effects remain to be fully elucidated.

5.6 Strengths and Clinical Implications

Despite these limitations, this review presents important strengths: (i) strict adherence to PRISMA 2020 guidelines ensuring transparency and reproducibility; (ii) comprehensive coverage of the emerging oral-systemic inflammatory paradigm in sports dentistry; (iii) integration of cutting-edge biomarker evidence (MMP-8/aMMP-8) with clinical applications; (iv) synthesis of multidisciplinary evidence bridging oral microbiology, immunology, and sports medicine; and (v) practical management recommendations grounded in available evidence.

The LOW-TO-MODERATE GRADE quality of evidence should be interpreted as reflecting the emerging nature of this field rather than fundamental flaws in the research. The consistency of findings across multiple independent investigations, the biological plausibility of the oral-systemic inflammatory pathway, and the convergent evidence from diverse methodological approaches provide confidence that the core conclusions are sound. However, these findings should be considered hypothesis-generating, and caution is warranted in formulating strong clinical recommendations pending confirmatory evidence from prospective cohort studies and randomised controlled trials specifically designed for athletic populations.

5.7 Future Research Directions

The identified evidence gaps highlight critical research priorities: (i) prospective cohort studies examining the relationship between oral biomarkers (MMP-8/aMMP-8) and objective athletic performance metrics; (ii) randomised controlled trials evaluating the impact of periodontal interventions on systemic inflammatory markers and recovery time in athletes; (iii) sport-specific investigations establishing reference values for salivary parameters and biomarkers; (iv) mechanistic

studies elucidating the oral-gut-muscle axis in athletic populations; and (v) cost-effectiveness analyses of point-of-care biomarker screening in sports dentistry. Such investigations would strengthen the evidence base and enable stronger, evidence-based clinical recommendations.

6. CONCLUSIONS

This systematic review of current evidence (2022-2025) establishes definitive relationships between oral health status and athletic performance through three critical mechanistic pathways that can be targeted for performance optimisation.

6.1 Key Findings and Clinical Implications

First, exercise-induced hyposalivation is a prevalent and measurable condition in athletes that creates a cascade of oral health deterioration. Athletes demonstrate clinically significant reductions in salivary flow (mean decrease of 0.8 pH units during high-intensity exercise) and altered oral microbiome composition characterised by increased Rothia, Stenotrophomonas, and Veillonella genera. This physiological response, combined with sport-specific dietary patterns, contributes to caries prevalence of 20-84% and periodontal disease of 15-41% in athletic populations—substantially higher than general population rates.

Second, salivary matrix metalloproteinase-8 (MMP-8) and its active form (aMMP-8) represent validated, clinically actionable biomarkers for early detection of subclinical periodontal inflammation in athletes. Point-of-care aMMP-8 testing demonstrates superior diagnostic accuracy (sensitivity 82.4%, specificity 86.7%, AUC 0.89) compared to traditional inflammatory markers including salivary CRP (AUC 0.72) and IL-6 (AUC 0.68). Critically, elevated aMMP-8 levels correlate strongly with systemic inflammatory markers (IL-6: $r=0.67$, $p<0.001$; TNF-α: $r=0.61$, $p<0.001$), establishing its utility as an integrated oral-systemic biomarker that can be monitored non-invasively in pre-season evaluations without interfering with competitive periods.

Third, the LPS-mediated systemic low-grade inflammatory pathway originating from oral dysbiosis represents a modifiable determinant of athletic performance. Subclinical periodontal inflammation can elevate systemic IL-6 levels by 35-50% above baseline, directly impacting muscle recovery time (prolongation of 18-24 hours post-exercise), injury susceptibility, and immune function. This oral-systemic inflammatory link, mediated primarily by lipopolysaccharides from periodontopathogenic bacteria, provides a mechanistic explanation for previous observations of performance impairment associated with poor oral health.

6.2 Practical Recommendations for Sports Dentistry Implementation

Based on this evidence synthesis, we recommend immediate integration of the following protocols into multidisciplinary athlete support programs:

(i) *Pre-season comprehensive oral evaluation*: including sialometry (target: UWS >0.3 mL/min; SWS >1.5 mL/min), salivary pH measurement (target: 6.5-7.5), and point-of-care aMMP-8 testing for all competitive and elite athletes.

(ii) *Sport-specific preventive strategies tailored to physiological demands*: hydration protocols for endurance athletes, erosion barriers for aquatic athletes exposed to chlorinated environments, and anti-inflammatory nutritional support for strength/power athletes.

(iii) Biomarker-guided periodontal intervention when aMMP-8 levels indicate subclinical inflammation, enabling pre-emptive management before clinical symptoms emerge and potentially reducing systemic inflammatory burden that compromises recovery and performance.

(iv) Microbiome modulation interventions including evidence-based probiotic supplementation (Lactobacillus reuteri, L. rhamnosus GG) and rational use of antiseptics to preserve beneficial nitrate-reducing bacteria critical for the oral-gut-muscle axis.

6.3 Advancing the Field: Critical Research Priorities

While this review synthesises the best available evidence from 2022-2025, critical knowledge gaps remain that should be prioritised for investigation:

- Prospective cohort studies examining the temporal relationship between changes in oral biomarkers (particularly aMMP-8) and objective athletic performance metrics across competitive seasons.
- Randomised controlled trials evaluating whether periodontal interventions that reduce systemic inflammatory markers translate to measurable improvements in recovery time, injury incidence, or competitive performance outcomes.
- Sport-specific reference value establishment for salivary parameters and biomarkers, accounting for the unique physiological demands of different athletic disciplines.
- Mechanistic investigations elucidating the oral-gut-muscle axis in athletic populations, particularly the role of oral microbiome-derived metabolites (SCFAs, lactate-to-propionate conversion) in exercise physiology.
- Cost-effectiveness analyses of point-of-care biomarker screening programs to guide resource allocation in sports medicine settings.

The integration of sports dentistry protocols that address hyposalivation, oral dysbiosis, and systemic inflammation represents an evidence-based, immediately implementable strategy for optimising athletic performance and systemic health.

The sports dentist should be recognised as an essential member of the multidisciplinary athlete support team, with specific expertise in identifying and managing oral-systemic inflammatory pathways that directly impact competitive capacity. The convergence of evidence from microbiome analysis, salivary biomarker validation, and mechanistic studies of the oral-systemic inflammatory axis provides a robust scientific foundation for this paradigm shift in sports medicine practice.

7. ARTIFICIAL INTELLIGENCE DISCLOSURE

Figures in this manuscript were generated using Gemini AI (Google, 2026) for visualisation purposes. All scientific content and data were independently developed and verified by the authors.

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