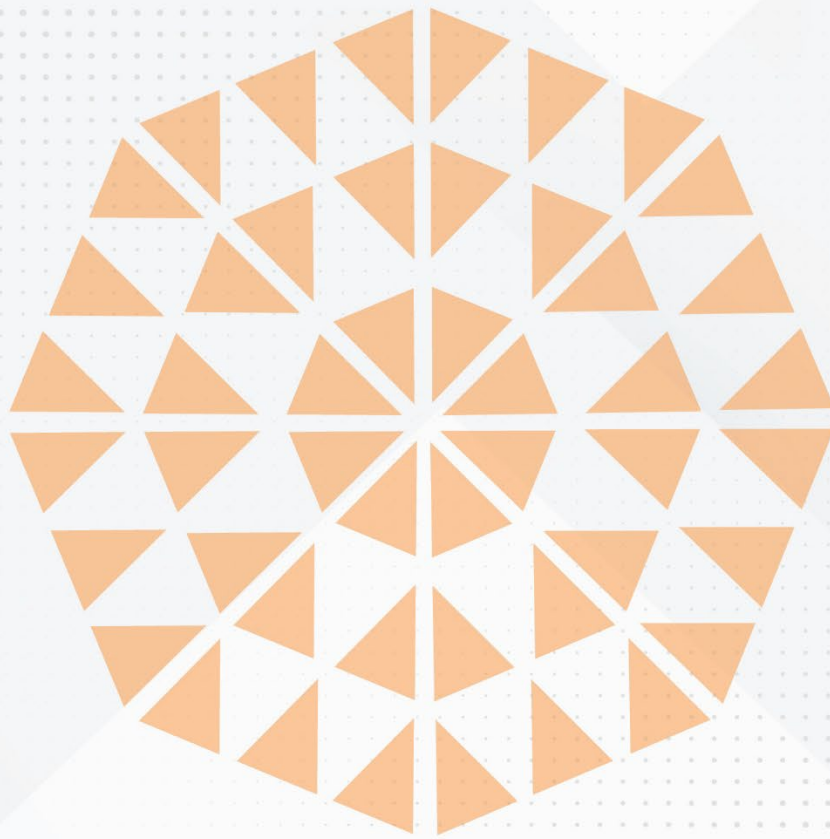


DENTAL BITES

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PERIODONTICS PUBLIC HEALTH



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DENTAL COLLEGE



INNOVATION AND
ENTREPRENEURSHIP
DEVELOPMENT CENTRE



KMCT Medical College Campus,
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Editorial

Dear Readers,

The concept of One Health reminds us that human health is closely connected with the health of animals and the environment in which we live. In today's world, many diseases are no longer limited to a single cause or a single system. They are influenced by multiple factors such as environmental changes, lifestyle habits, food safety, microbial resistance, and interactions between humans and animals. Because of this growing complexity, healthcare professionals must look beyond individual disciplines and adopt a more collaborative and comprehensive approach to health.

Traditionally, dentistry was mainly focused on diagnosing and treating diseases of the teeth and gums. However, modern scientific evidence clearly shows that oral health is closely linked with overall systemic health. Conditions such as periodontal disease have strong associations with diabetes, cardiovascular diseases, respiratory infections, adverse pregnancy outcomes, and other chronic conditions. Similarly, oral infections can influence general health, and systemic diseases can also affect oral tissues. This two-way relationship highlights the importance of integrating dentistry into the larger framework of total healthcare.

Environmental factors also play a significant role in oral health. Water quality, nutrition, pollution, antibiotic usage, and lifestyle habits directly influence the occurrence and progression of oral diseases. The increasing concern about antimicrobial resistance is another important issue that requires attention from dental professionals as responsible prescribers of antibiotics. These challenges further emphasize the relevance of adopting the One Health approach in dental education, clinical practice, and research.

The One Health concept encourages collaboration between different disciplines such as dentistry, medicine, veterinary science, environmental science, public health, and life sciences. When professionals from different areas work together, they are able to better understand disease patterns, improve preventive strategies, and develop more effective healthcare solutions. Such interdisciplinary cooperation is especially important in addressing emerging health challenges and improving community well-being.

At KMCT Dental College, we believe that research should actively move in this broader and integrated direction. As an academic institution committed to excellence in education, patient care, and community service, we have a responsibility to promote research that connects oral health with general health and environmental sustainability. Faculty members and students should be encouraged to explore innovative and interdisciplinary research topics that contribute not only to scientific knowledge but also to practical improvements in community health.

The One Health approach also strengthens our commitment to preventive dentistry and community-oriented healthcare. By understanding the relationship between environmental factors, lifestyle practices, systemic health conditions, and oral diseases, we can design better outreach programs, awareness campaigns, and preventive strategies that benefit society at large.

I encourage our faculty and students to take up meaningful research initiatives aligned with the principles of One Health. Even small, well-planned studies focusing on community needs, preventive care, sustainable practices, and responsible clinical approaches can create a lasting impact on public health.

Let this issue of our journal serve as a reminder and inspiration for all of us to think beyond traditional boundaries, collaborate across disciplines, and contribute towards research that supports healthier individuals, healthier communities, and a healthier environment. Through such collective efforts, we can move forward towards a more responsible and holistic vision of healthcare for the future.

With warm regards,
Dr. Manoj Kumar K. P, Principal



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Review

EFFECTS OF PERIODONTITIS ON CANCER OUTCOMES IN THE ERA OF IMMUNOTHERAPY

*Dr. Joel George James, **Dr. Harish Kumar V V, *** Dr Saumiya Gopal,
****Dr Anish Varkey, **** Dr Shruthi Nambiar, *****Dr Sunanda S

Abstract:

Periodontitis is a chronic inflammatory disease of the gums that extends beyond tooth loss, with the potential to disrupt immune regulation and influence patient responses to modern cancer immunotherapies. This review outlines, in accessible terms, how periodontal infection alters host immune defenses, the role of key pathogens such as *Porphyromonas gingivalis* in modulating immunity and the gut microbiome, and the implications of these changes for cancer treatment outcomes. Chronic periodontitis can promote sustained systemic inflammation, overlapping with organs and pathways commonly involved in immune checkpoint inhibitor-related adverse effects. Recognizing this oral-systemic connection highlights opportunities for interdisciplinary collaboration among dental professionals, oncologists, and immunologists, with the potential to enhance cancer care through improved periodontal health.

Keywords: *Periodontitis; Oral microbiome; Immune dysregulation; Porphyromonas gingivalis; Cancer immunotherapy; Systemic inflammation*

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Introduction

Periodontitis starts as a build-up of dental plaque but can progress into a deep-seated infection that destroys the supporting

tissues of the teeth.¹ Over time, this chronic inflammation helps harmful bacteria flourish and continuously stimulates the immune system.² Instead of remaining as a



local gum problem, periodontitis can release bacteria, toxins, and inflammatory molecules into the bloodstream, influencing distant organs.³ At the same time, cancer immunotherapy—especially immune checkpoint inhibitors—relies on finely tuned immune responses, which can be disturbed by any chronic inflammatory condition.⁴ These converging pathways make periodontitis highly relevant in the era of immunotherapy.⁵

From plaque to systemic inflammation

In health, the mouth hosts a balanced community of bacteria that live in harmony with the body.⁶ When plaque accumulates and oral hygiene is poor, this balance is lost and a complex biofilm forms along the gumline and within periodontal pockets.¹ As this biofilm matures, it becomes enriched with aggressive, mainly Gram-negative anaerobic bacteria that thrive in the oxygen-poor depths of the pocket.⁶ *Porphyromonas gingivalis* is one of the best-studied species and is often described

as a “keystone” pathogen because it can reshape the whole microbial community and the immune response, even when present in relatively low numbers.²

The body reacts to this persistent infection with an ongoing immune response, involving neutrophils, macrophages, T cells, and a cascade of inflammatory mediators such as interleukin-6 and C-reactive protein.⁷ In many people, this response fails to fully clear the bacteria but still causes collateral damage to the surrounding connective tissue and bone, leading to tooth mobility and loss.¹ Importantly, the inflamed and ulcerated pocket surface provides a doorway for bacteria and their products to enter the bloodstream repeatedly, a process known as transient bacteraemia.⁸ This repeated challenge can help sustain low-grade systemic inflammation, which is now recognised as a contributor to several chronic diseases.³



How a mouth infection talks to the immune system

P. gingivalis has evolved sophisticated tools called virulence factors that allow it to survive, spread, and confuse the host immune system.² These include protein-cutting enzymes known as gingipains, cell-surface fimbriae that help the bacteria stick to tissues and other microbes, outer membrane vesicles that package toxins, and inflammatory molecules such as lipopolysaccharides.² Gingipains can hijack the complement system, a key part of innate immunity, by generating signals like the C5a fragment that fuel inflammation but at the same time interfere with efficient bacterial killing.⁹ By diverting complement–toll-like receptor signalling, *P. gingivalis* promotes a state where inflammation is high but true clearance of infection is poor.⁹ In parallel, periodontal infection has been linked to increased activity of immune brakes such as the PD-1/PD-L1 and CTLA-4 pathways in gingival tissues and circulating immune cells. These

pathways normally prevent excessive immune damage, but in the setting of chronic infection they can contribute to immune exhaustion and allow bacteria to persist. *P. gingivalis* fimbriae and vesicles appear to stimulate cells to express more PD-1 and PD-L1, reinforcing this inhibitory environment.² Similar immune checkpoints are the very targets of modern cancer immunotherapy, suggesting that long-standing periodontitis might influence systemic immune tone in ways that matter for tumour control.⁴

The gut connection: Oral bacteria downstream

The effects of oral dysbiosis are not confined to the mouth and blood.⁸ Animal and human studies suggest that periodontal pathogens can also travel to and reshape the gut microbiome.¹⁰ Experimental models where *P. gingivalis* is given orally show changes in gut bacterial composition, including increases in groups such as *Bacteroidales* and *Prevotella* that have



been associated with weaker responses to immune checkpoint blockade in cancer.¹¹ Exploratory stool studies in people with periodontal disease have similarly detected oral taxa in the gut and reduced microbial diversity compared with healthy individuals.¹²

In the immunotherapy field, the gut microbiome has emerged as a major factor influencing who responds to checkpoint inhibitors and who develops severe side effects.¹³ Certain gut bacterial profiles are enriched in “responders,” whereas others, including some species common in periodontitis, are more frequent in “non-responders.”¹³ This overlap raises the hypothesis that untreated periodontitis, by seeding and reshaping the gut microbiota, might indirectly tilt the balance away from an optimal immunotherapy response.²

Shared Pathways: Periodontitis and Immune-Related Toxicities

Immune checkpoint inhibitors, such as anti-PD-1, anti-PD-L1, and anti-CTLA-4

antibodies, unleash T cells against cancer but can also trigger autoimmune-like side effects in many organs.⁴ These immune-related adverse events include colitis, hepatitis, thyroid disorders, myocarditis, pneumonitis, arthritis, and more.⁴ Interestingly, periodontitis has been linked epidemiologically and mechanistically with several of these same systemic inflammatory conditions.³ For example, experimental work suggests that oral pathogens can contribute to myocarditis in animal models, alter gut barrier integrity and promote colitis-like inflammation, and influence insulin resistance and pancreatic islet health relevant to diabetes.¹⁴ Beyond specific organs, both periodontitis and checkpoint toxicities share themes of immune dysregulation, barrier disruption, and chronic cytokine production.³ Patients with periodontitis often show raised systemic levels of inflammatory mediators such as interleukin-6 and fibrinogen, as well as altered leukocyte profiles.⁷ Such a “primed” inflammatory state might lower



the threshold for developing severe immune-related side effects once immunotherapy is started, although this has not yet been fully tested in large clinical trials.¹⁵ The possibility that a common oral disease could influence both cancer outcomes and toxicity risk is an important and emerging area of research.²

Cancer outcomes and the promise of oral care

Cancer care is becoming increasingly reliant on immunotherapy, yet only a fraction of patients currently achieve durable responses.¹⁶ At the same time, periodontitis remains highly prevalent, especially among older adults and populations with limited access to dental care.¹ Socioeconomic and racial disparities in oral health could therefore intersect with differences in access to and benefit from immunotherapy.¹⁵ The reviewed evidence suggests that treating periodontitis might not only protect oral function and quality of life, but also help rebalance systemic

immunity and potentially improve the safety and effectiveness of cancer immunotherapy.³ Standard periodontal therapy focuses on mechanical removal of plaque and tartar through scaling and root planing, supported by good home oral hygiene.¹⁷ Clinical guidelines already recommend these approaches to control inflammation and prevent tooth loss.¹⁷ Beyond the mouth, systematic reviews indicate that effective periodontal treatment can reduce systemic inflammatory markers and improve cardiometabolic profiles, hinting at broader health benefits.¹⁸ Future strategies may include targeted therapies against key pathogens such as *P. gingivalis* or drugs that actively promote resolution of inflammation rather than simply suppressing it.¹⁸ Whether such interventions can meaningfully modify cancer immunotherapy responses remains an open but exciting question.²

Conclusion

Periodontitis extends beyond a localized



oral condition and represents a chronic inflammatory disease with the capacity to modulate both local and systemic immune responses.¹ Through complex interactions involving bacterial virulence factors, immune checkpoint regulation, complement activation, and microbiome alterations, periodontal disease may contribute to systemic inflammatory disorders and influence the efficacy of cancer immunotherapy.² Recognizing the oral cavity as an integral component of the broader immunological environment underscores the need for closer collaboration between dental and medical disciplines, particularly in patients undergoing or preparing for immune checkpoint inhibitor therapy.⁴ As evidence continues to emerge, the incorporation of routine periodontal evaluation and timely intervention into oncology care pathways may offer a practical, non-pharmacological strategy to enhance therapeutic outcomes and reduce treatment-related complications in an ageing, multimorbid population.³

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Review

Growth Factors and Biomarkers in Periodontal Therapy

*Dr Anjali K, ** Dr Harish Kumar V V, **Dr Saumiya Gopal, ***Dr Navia George, *** Dr Anish Varkey, ***Dr Shruthi Nambiar

Abstract:

Growth factors and host-response biomarkers are emerging as key adjuncts for improving diagnosis, risk assessment, and regenerative outcomes in periodontal therapy. This review synthesizes current evidence on recombinant and endogenous growth factors such as platelet-derived growth factor, fibroblast growth factor-2, bone morphogenetic proteins, and transforming growth factor- β as biological mediators that modulate cell proliferation, chemotaxis, angiogenesis, and matrix synthesis to enhance periodontal regeneration in intrabony and furcation defects. Parallel advances in biomarker science have positioned gingival crevicular fluid and saliva as accessible sources of inflammatory, degradative, and regenerative markers, including interleukins, tumour necrosis factor- α , matrix metalloproteinase-8, and β -glucuronidase, which correlate with disease activity, healing dynamics after non-surgical therapy, and the risk of future breakdown. The review highlights how multiplex and ‘omics’ platforms integrate microbial profiles with host-derived biomarkers to generate site-specific inflammatory signatures that can guide personalized periodontal treatment planning and monitoring. Finally, translational challenges and future directions are discussed, including the optimization of delivery systems and dosing for growth factor-based bioengineering, the validation of robust biomarker panels with prognostic value, and the development of chairside assays that couple biologic modifiers with real-time monitoring to achieve predictable, patient-tailored periodontal regeneration.

Keywords: *Growth factors, Personalized treatment*

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Introduction

Growth factors and biomarkers have emerged as pivotal tools in modern periodontal therapy, helping clinicians move beyond traditional mechanical treatment toward biologically driven, precision-based care.¹ These molecules play essential roles in promoting tissue regeneration, predicting disease activity, and monitoring therapeutic outcomes.² This article highlights the major growth factors and biomarkers relevant to periodontal regeneration and diagnostics, explaining their clinical significance in a simplified, reader-friendly format.³

Periodontal disease is a chronic inflammatory condition characterized by destruction of supporting periodontal tissues, including gingiva, periodontal ligament, cementum and alveolar bone.⁴ While conventional therapy focuses on plaque control and scaling, achieving true regeneration and accurately detecting early disease activity remain key challenges.⁵

Growth factors stimulate natural tissue repair by enhancing cellular activity, angiogenesis, and matrix synthesis.⁶ Biomarkers, on the other hand, provide objective molecular indicators of inflammation, bone loss, and healing.⁷ Integrating these two approaches offers a

powerful combination for personalized and regenerative periodontal care.⁸

Growth Factors: Biological Role in Periodontal Tissues

Growth factors are naturally occurring polypeptides that act as signaling molecules, regulating cellular behaviour during development, wound healing, and tissue regeneration.⁸ In periodontal tissues, they play a crucial role in coordinating the repair of gingiva, periodontal ligament, cementum, and alveolar bone following injury or therapy.⁹

These molecules exert their effects by binding to specific cell surface receptors and activating intracellular signaling pathways that control gene expression. Key cellular responses include chemotaxis, mitogenesis, angiogenesis, and extracellular matrix synthesis.¹⁰

Major Growth Factors in Periodontal Therapy

Platelet-derived growth factor (PDGF) is one of the most extensively studied growth factors in periodontology. It stimulates fibroblast proliferation, enhances collagen synthesis, and promotes angiogenesis. Recombinant human PDGF-BB has demonstrated significant improvements in periodontal regeneration when used with



bone grafts.¹¹

Transforming Growth Factor- β (TGF- β)

regulates inflammation and promotes the formation of connective tissue by stimulating collagen and fibronectin production. It also modulates immune responses, making it crucial for balanced wound healing.¹²

Fibroblast Growth Factors (FGFs)

support fibroblast migration and angiogenesis, contributing to soft-tissue healing and periodontal ligament regeneration.¹³

Insulin-Like Growth Factors (IGFs)

promote osteoblast proliferation and matrix formation, thereby supporting alveolar bone regeneration.¹⁴

Vascular Endothelial Growth Factor

(VEGF) is essential for neovascularization, ensuring adequate blood supply to healing periodontal tissues.¹⁵

Growth Factors in Clinical Periodontal Regeneration

Growth factors can be delivered to periodontal defects through recombinant proteins, biomaterial carriers, or autologous platelet concentrates.¹⁶ Products such as platelet-rich plasma (PRP) and platelet-rich fibrin (PRF) release multiple growth factors

in a sustained manner, enhancing both hard and soft tissue healing.¹⁷

Clinical studies have shown that growth factor-based therapies result in greater bone fill, improved attachment levels, and enhanced wound stability compared to conventional approaches alone.¹¹ However, variability in outcomes highlights the need for proper case selection and standardized protocols.¹⁶

Biomarkers in Periodontal Disease

Biomarkers are measurable biological molecules that indicate normal or pathological processes or responses to therapeutic interventions.¹⁸ In periodontology, biomarkers provide insight into disease activity, host response, and treatment outcomes.

Common periodontal biomarkers include inflammatory cytokines such as interleukin-1 β and tumor necrosis factor- α , enzymes like matrix metalloproteinase-8, and bone metabolism markers.⁶ These biomarkers are commonly detected in gingival crevicular fluid, which reflects local periodontal tissue status.⁴

Biomarkers in Periodontal Therapy and Monitoring



Changes in biomarker levels before and after periodontal therapy reflect the biological response to treatment. Successful non-surgical periodontal therapy has been shown to reduce inflammatory and tissue-destructive biomarkers while increasing markers associated with healing and resolution.¹⁹

Systemic biomarkers such as C-reactive protein and growth differentiation factor-15 have also been linked to periodontal inflammation, emphasizing the connection between periodontal health and systemic conditions.²⁰ Biomarkers therefore hold promise for early diagnosis, risk assessment, and personalized periodontal care.¹⁸

Conclusion

Growth factors and biomarkers have significantly enhanced the biological understanding of periodontal disease and its treatment. Growth factors facilitate regeneration by stimulating cellular activities essential for tissue repair, while biomarkers provide measurable indicators of disease activity and therapeutic success. Integrating these biological tools into clinical practice offers opportunities for more precise diagnosis, targeted therapy, and improved regenerative outcomes. Continued research and clinical validation

will further establish their role in evidence-based periodontal therapy.

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Review

Nanotechnology in Periodontics: Nanodrugs, Nanocoatings and Targeted Antimicrobials

*Dr Sarika H, **Dr V C Santhosh, **Dr Saumiya Gopal, ***Dr Aparna T K, ****Dr Risvana S, ****Dr Aswathi S

Abstract:

Nanotechnology is opening new and exciting possibilities in the field of periodontics by bringing therapy closer to the disease site with greater precision and effectiveness. Conventional periodontal treatments often face limitations in eliminating deep-seated biofilms and delivering drugs in adequate concentrations. Nano-based systems, because of their extremely small size and unique properties, allow better penetration, controlled drug release, enhanced antimicrobial action, and improved tissue healing. This review explores the evolving role of nanodrugs, nanocoatings, and targeted antimicrobial nanoparticles in periodontal care.

Key words: *Nanoparticles, Nanocoatings, Targeted antimicrobials*

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Introduction

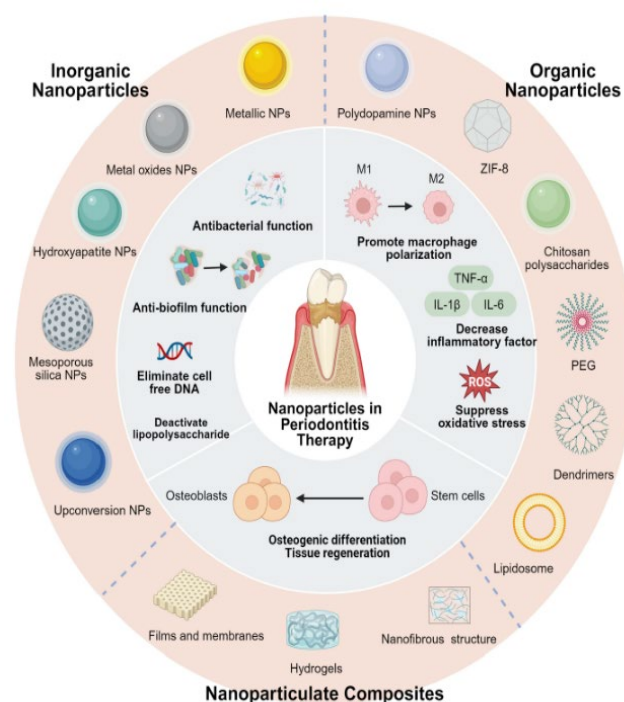
Nanotechnology has emerged as a transformative tool in periodontal therapy, enabling improved antimicrobial action, enhanced drug delivery, and advanced regenerative strategies.¹ The nanoscale dimension allows materials to exhibit unique biological, mechanical, and physicochemical properties that make them

highly effective for targeted periodontal applications.² Nanodrugs, nanocoatings, and nanoparticle based antimicrobials offer new pathways to control biofilms, modulate inflammation, and promote hard and soft tissue healing with greater predictability.³ This review summarizes current developments in nanotechnology relevant to periodontics, presenting an integrated

overview of therapeutic potential, clinical implications, and future directions.⁴

Periodontitis is a multifactorial chronic inflammatory disease affecting the gingiva, periodontal ligament, cementum, and alveolar bone.⁵ Conventional therapies such as scaling and root planing often fail to eliminate pathogens residing deep within biofilms or inaccessible anatomical niches.⁶ The limitations of systemic antibiotics resistance, inadequate concentration at the target site, and adverse effects create a need for more advanced therapeutic approaches.³

Nanotechnology provides highly promising solutions due to the unique behaviour of materials at <100 nm, allowing enhanced drug loading, controlled release, tissue penetration, and antimicrobial activity.¹ Nanomaterials such as metallic nanoparticles, polymeric carriers, nanofibers, and nanocoatings display remarkable mechanical and biological characteristics that significantly improve periodontal diagnostics, drug delivery, and regenerative outcomes.⁸ Their ability to self-assemble, integrate with tissues, and interact at the molecular scale has made nanotechnology a critical pillar of emerging periodontal innovations.⁷



Nanodrug delivery system in periodontitis

Nanocarriers exhibit superior stability, tissue permeability, and controlled-release behaviour, making them ideal for periodontal drug delivery.³ These nano-systems overcome limitations of conventional therapeutics by maintaining therapeutic levels within periodontal pockets and improving bioavailability.

Common nanodrug systems include:

- Polymeric nanoparticles engineered for biocompatibility and sustained release of antimicrobials and anti-inflammatory agents.²
- Nanospheres and nano capsules – enhance solubility and protect drugs from degradation.³



- Dendrimers – highly branched nanostructures capable of precise drug attachment and release.³
- Nanogels – hydrophilic networks that swell and release embedded drugs in response to local environmental stimuli.³
- Liposomes – lipid vesicles ideal for encapsulating hydrophilic and hydrophobic agents for targeted periodontal delivery.³

Calcium and zinc loaded polymeric nanoparticles demonstrate biomimetic mineralization, enhanced cell compatibility, and antibacterial effects, making them suitable for regenerative periodontal therapy.² Metallic nanoparticles further improve antimicrobial outcomes through membrane disruption and oxidative damage to pathogens.⁶

Nanodrug delivery therefore, provides controlled, localised, and efficient therapeutic platforms, minimizing systemic exposure and maximizing clinical results.³

Nanocoatings for Regenerative Periodontal Therapy

Nanostructured coatings improve the biological performance of membranes, scaffolds, and implant surfaces, making them vital in regenerative periodontics.⁸

Key nanocoating applications include:

- **Nano-hydroxyapatite coatings** that enhance osteoconduction and accelerate bone formation.⁸
- **Nanofiber membranes** that mimic the native extracellular matrix, supporting fibroblast attachment and periodontal ligament regeneration.⁴
- **Metallic nanocoating** that provides antibacterial protection for implant surfaces and regenerative scaffolds.⁶
- **Self-assembled nanolayers** offering superior mechanical and biological properties through molecular-level interactions.⁸

Nanofiber-based guided tissue regeneration (GTR) membranes provide an ideal microenvironment for periodontal cells by combining mechanical strength with biological cues.⁵ Recent studies underscore the significant potential of bioactive nanomaterials to enhance periodontal tissue regeneration by promoting osteogenesis, supporting periodontal ligament repair, and providing favorable interactions within the periodontal microenvironment.¹⁰

Targeted Antimicrobial Nanoparticles

Periodontal pathogens organized in biofilms are often resistant to conventional antimicrobials. Nanoparticles overcome this by delivering potent antibacterial



action and penetrating biofilm matrices.⁵

Metallic nanoparticles

Silver, gold, and zinc oxide nanoparticles demonstrate exceptional antimicrobial properties due to their surface reactivity, production of reactive oxygen species (ROS), and interaction with bacterial membranes.⁶ They show effectiveness against periodontopathogens such as *P. gingivalis* and *T. denticola*.⁵

Polymeric antimicrobial nanocarriers

Polymeric nanoparticles loaded with antibiotics or natural antimicrobials release drugs in a sustained manner, maintaining prolonged therapeutic levels within periodontal pockets.³

Anti-inflammatory and antioxidant nanoparticles

Nanoparticles modulate macrophage activity, reduce ROS burden and regulate destructive host responses, thereby preventing progressive tissue breakdown.⁵

Nanodiagnostic systems & nanobiosensors

Nanobiosensors detect biomarkers in saliva or gingival crevicular fluid for early diagnosis of periodontal disease and monitoring of treatment response.⁷

Nanorobotics (conceptual future direction)

Micro-scale robotic systems have been proposed for autonomous plaque removal and targeted drug delivery, representing a futuristic extension of nanotechnology in periodontics.⁷

Targeted nanomaterials thus address both microbial dysbiosis and the destructive inflammatory cascade responsible for periodontal breakdown.⁵

Conclusion:

Nanotechnology is reshaping periodontal therapy by offering solutions that overcome the limitations of conventional mechanical and pharmacological approaches.¹ Nanodrugs, nanocoatings and targeted antimicrobial nanoparticles provide improved effectiveness, site specificity and regenerative capability.⁵ Recent advances in nanocarrier-based delivery systems have demonstrated improved drug stability, controlled release kinetics, and enhanced penetration into diseased periodontal tissues, thereby overcoming many limitations associated with conventional therapeutic formulations.⁹

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Review article

SIMULATION LABS IN DENTAL EDUCATION: FROM PHANTOM HEADS TO AI-DRIVEN FUTURES

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Abstract

Simulation laboratories have become a cornerstone of modern dental education, transforming preclinical training from traditional phantom heads and extracted teeth to immersive virtual reality (VR) and hapticbased systems. This review synthesizes historical developments, current technologies, educational outcomes, and broader public health applications of simulation in dentistry. Early innovations such as DentSim and phantom-head manikins provided foundational skill training, while contemporary systems such as Simodont, HapTEL, and CAD/CAM-integrated VR simulators offer real-time feedback, enhanced dexterity, and objective assessment. Evidence from comparative studies demonstrates that simulation clinics improve student confidence and readiness for clinical practice, although performance outcomes remain mixed when compared with traditional laboratory environments. Beyond education, simulation modelling—including geographic information systems (GIS), spatial microsimulation, and agent-based modelling—extends applications into dental public health, enabling workforce planning and service accessibility analysis. Despite challenges related to cost, fidelity of force feedback, and curriculum integration, simulation laboratories represent a vital bridge between theoretical instruction and patient care. Future directions point toward AI driven adaptive simulators, integration with digital dentistry workflows, and expanded use in public health modelling, positioning simulation as a transformative force in dental education and practice.

Key words: *Simulation labs, Haptic based systems*

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Introduction

Dental education has long faced the challenge of preparing students for clinical practice in a safe yet realistic environment. Traditional preclinical training relied on extracted teeth and phantom head models, offering limited opportunities to replicate the complexity of real patient care. The first phantom head simulator was invented by Oswald Fergus and was used to teach oral anatomy and physiology.¹

The advent of simulation technologies marked a paradigm shift, enabling students to acquire technical skills, diagnostic acumen, and confidence before treating live patients. Early systems such as DentSim combined mannequin-based practice with digital visualization, while subsequent innovations introduced haptic feedback, virtual reality environments, and intelligent tutoring systems that expanded the scope of simulation-based learning.²

Simulation clinics, pioneered in institutions such as the University of Iowa, further enhanced realism by replicating operator settings with lifelike manikins. Comparative studies revealed that while traditional bench-top training often yielded higher technical scores, simulation clinics significantly improved student perceptions of clinical readiness and confidence.³

Recent perspectives emphasize the integration of advanced technologies such

as virtual reality simulators, CAD/CAM systems, and digital imaging into dental curricula, demonstrating improvements in clinical proficiency, decision making, and reduced learning curves among students.⁴ Beyond individual skill acquisition, simulation modelling has also been applied to dental public health. Geographic information systems, spatial microsimulation, and agent-based modelling provide innovative approaches to analysing workforce distribution, service accessibility, and oral health inequalities.⁵ The COVID-19 pandemic further accelerated the adoption of simulation-based education. With restrictions on patient contact and increased infection risks, dental schools worldwide relied on virtual reality simulators, haptic devices, and digital platforms to maintain preclinical training.

Educators reported that simulation became indispensable in sustaining skill acquisition during lockdowns.⁶

Studies from India similarly highlighted that the pandemic reshaped dental curricula, accelerating the adoption of blended learning models combining online theoretical instruction with simulation-based practice.⁷ These developments underscore the growing importance of simulation laboratories as essential components of contemporary dental education.



Historical development of simulation in Dentistry

Preclinical dental training in the nineteenth century began with exercises on extracted teeth before progressing to phantom head simulators. These early models allowed students to replicate clinical manipulations under faculty supervision, forming the foundation for structured skill acquisition.² The late twentieth century marked the introduction of computerized training systems such as DentSim, which combined mannequin-based simulation with three-dimensional visualization and infrared tracking. These systems provided real-time feedback on cavity preparations and procedural accuracy.

Institutions such as the University of Geneva further advanced simulation-based education by incorporating 3D computer simulations into dental curricula. Subsequent systems, including HapTEL and Simodont, introduced haptic feedback technology, enabling students to perceive tactile differences between enamel, dentine, and carious tissues.

This progression reflects a shift from traditional manual training toward immersive, technology-driven educational environments that closely simulate real clinical scenarios.

Table 1. Comparison of current virtual reality dental simulators

Simulator	Technical characteristics	Key strengths
DentSim	Mannequin-based simulator with real dental instruments, 3D visualization, and infrared tracking.	High realism with real-time performance feedback.
Geneva System	3D computer-based simulation used for teaching dental anatomy.	Enhances anatomical visualization and digital learning.
Virtual Education System for Dentistry	Integrates theoretical modules with phantom head clinical practice.	Structured evaluation and standardized learning outcomes.
IDEA (Individual Dental Education Assistant)	Pen-like device simulating a dental turbine handpiece.	Improves handpiece control and manual dexterity.
VRDTS (Virtual Reality Dental Training System)	VR-based simulator focusing on cavity preparation and restorative procedures.	Safe virtual practice of restorative techniques.
Iowa Dental Surgical Simulator	Provides tactile differentiation between enamel,	Enhances diagnostic ability and tactile perception.



Simulator	Technical characteristics	Key strengths
	dentine, and carious tissue.	
PerioSim	Periodontal simulation with a 3D virtual oral environment.	Focused training in periodontal probing and diagnostics.
HapTEL System	Haptic simulator with dual screens and foot pedal for speed control and tracking.	Real-time feedback on tissue removal and procedural progress.
VirDenT System	Combines virtual and augmented reality with an intelligent tutoring system.	Real-time procedural guidance and interactive learning.
Simodont	High-fidelity haptic dental simulator for multiple dental procedures.	Comprehensive hands-on simulation training.
Dentify	VR-based simulator with haptic pen and VR headset.	Immersive training with adjustable difficulty levels.

Current technologies in simulation labs

Modern simulation laboratories incorporate a variety of technologies designed to enhance preclinical dental training. Virtual reality simulators such as IDEA, VRDTS,

and Dentify create immersive environments where students perform procedures using haptic devices and VR interfaces while receiving real-time performance feedback.

Hybrid systems combine theoretical learning modules with practical phantom-head exercises, enabling structured skill development and objective assessment.

Haptic simulators such as PerioSim and the Iowa Dental Surgical Simulator allow students to perceive tactile differences between dental tissues and practice periodontal diagnostic techniques.

Integration with digital dentistry tools—including CAD/CAM systems, intraoral scanners, and digital radiography—further enriches simulation-based education and prepares students for contemporary clinical practice. ⁴

Although these technologies provide risk-free practice environments and allow repetitive training with objective evaluation, limitations remain. Issues such as cybersickness associated with VR headsets, insufficient force-feedback fidelity, and high infrastructural costs continue to challenge widespread implementation. ²

Educational outcomes and student performance

Several studies have examined the effectiveness of simulation-based training



in dental education.

A comparative study conducted at the University of Iowa evaluated student performance in simulation clinics and traditional laboratory settings over three years. Results demonstrated that students trained extensively in traditional bench-top environments sometimes achieved higher scores in certain technical tasks. However, students exposed to simulation clinics demonstrated improved performance in more complex procedures such as margin preparation.³

Importantly, students consistently reported greater confidence and preparedness for patient care following simulation-based training.

Additional research has shown that simulation technologies enhance clinical proficiency, decision-making abilities, and knowledge retention while reducing the learning curve for newly graduated dentists.

4

These findings suggest that simulation laboratories complement traditional training methods rather than replacing them entirely.

Simulation in dental public health

Beyond individual clinical training, simulation modelling has also been applied to dental public health. Geographic information systems have long been used to

map dental service distribution and identify underserved populations. Spatial microsimulation techniques enable the creation of synthetic populations to analyse behavioural factors such as dental attendance patterns and oral hygiene practices.⁵

Agent-based modelling provides further insights by simulating dynamic interactions between patients, dental providers, and healthcare systems.

These approaches allow researchers to evaluate policy interventions, predict service demand, and plan workforce distribution more effectively.

By integrating simulation modelling into dental public health research, educators and policymakers can better address disparities in oral health access and improve population-level outcomes.

Challenges and limitations

Despite the significant benefits of simulation-based education, several challenges remain. Technical limitations include inadequate replication of soft tissue deformation, limited tactile realism, and potential discomfort associated with prolonged use of VR devices.²

Educational challenges include the need for faculty training, curriculum restructuring, and standardized assessment frameworks to effectively integrate simulation



technologies into dental programs.

Economic barriers also play a major role, as advanced VR and haptic simulators require substantial financial investment for purchase, maintenance, and infrastructure. Furthermore, simulation training must be balanced with real patient interactions to ensure students develop essential communication skills, empathy, and clinical judgement.

Simulation in dental education in India

While many dental schools in Europe and North America have incorporated advanced simulation technologies into their curricula, adoption in India has been relatively limited. Most dental institutions continue to rely primarily on phantom head simulators and traditional preclinical laboratories, with minimal exposure to VR-based training systems.

The COVID-19 pandemic highlighted this gap, as many institutions faced challenges in providing safe alternatives to patient-based clinical training. Surveys of Indian dental educators indicated that simulation-based teaching remains in its early stages due to infrastructural limitations and high equipment costs.⁷

Although awareness regarding the benefits of simulation technologies is increasing, their implementation remains largely

restricted to a small number of private institutions with access to advanced resources.⁸ Greater policy support, funding, and faculty training initiatives are necessary to promote widespread integration of simulation laboratories into dental education across India.

Future directions

The future of simulation in dental education will likely involve greater integration of emerging technologies and innovative pedagogical approaches. Artificial intelligence-driven adaptive simulators may provide personalized feedback tailored to individual student performance and learning needs.

Advances in virtual reality, augmented reality, and haptic technologies will further improve simulation fidelity and realism. Integration with digital dentistry tools such as CAD/CAM systems, intraoral scanners, and three-dimensional printing will align simulation training more closely with modern clinical practice.

Simulation modelling will also continue to expand in dental public health research, supporting workforce planning, service accessibility analysis, and policy development.

Reducing the cost of simulation systems will be essential to ensure accessibility for dental schools in resource-limited settings.



Conclusion

Simulation laboratories have become indispensable components of modern dental education, bridging the gap between theoretical knowledge and clinical practice. These technologies enhance skill acquisition, improve student confidence, and provide safe environments for repeated practice.

Although challenges related to cost, technological fidelity, and curricular integration remain, ongoing innovations in artificial intelligence, virtual reality, and digital dentistry are expected to further strengthen the role of simulation based education. By embracing these advancements, dental institutions can better prepare future clinicians while also contributing to improved oral health outcomes at both individual and population levels.

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Review

Recent Advances in Guided Tissue and Bone Regeneration: Membranes, Grafts, and Emerging Technologies

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Abstract:

Guided tissue regeneration (GTR) and guided bone regeneration (GBR) have progressed from the use of passive barrier membranes and inert graft materials to advanced bioactive and multifunctional regenerative systems. Recent advances in material science and fabrication technologies have enabled the development of resorbable and functionalized membranes, composite and ion-doped grafts, bioactive ceramics, and scaffold systems that actively modulate cellular responses, angiogenesis, immune regulation, and tissue maturation. The incorporation of biologics, including platelet concentrates and growth factors, along with innovations in scaffold design, injectable biomaterials, and three-dimensional (3D) printing, has further enhanced defect adaptation and regenerative predictability. This review highlights contemporary advances in membranes, bone graft materials, biologic adjuncts, and emerging fabrication techniques relevant to periodontal, alveolar, and maxillofacial regeneration, while addressing current clinical trends, evidence gaps, and translational challenges such as cost, handling characteristics, regulatory issues, and the need for long-term clinical outcomes. Overall, modern GTR and GBR approaches are evolving toward smart, patient-specific, and biologically instructive systems aimed at predictable restoration of functional tissue architecture.

Keywords: *Guided tissue regeneration, Bone grafts, Emerging technologies*

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Introduction

Guided tissue regeneration (GTR) and its counterpart, guided bone regeneration



(GBR), have undergone a significant evolution from simple passive barrier membranes and inert bone fillers to sophisticated bioactive systems that guide and stimulate healing.¹ Over the past few years, new materials and design strategies have emerged: resorbable membranes incorporating growth factors, multifunctional scaffolds with tailored porosity, ion-doped ceramics, composite grafts with polymers and bioactive glass, and even intraoperative 3D printing of grafts.² These innovations promise improved predictability, faster healing, and less morbidity in bone- and periodontal-regeneration procedures.³ Yet practical issues such as cost, clinician familiarity, long-term data, and regulatory pathways remain.⁴ In this review, we summarise the recent advances in membranes and grafting materials, discuss emerging manufacturing technologies, and explore the translational challenges ahead.

When alveolar bone, periodontal attachment or cranio-maxillofacial bone is lost due to disease, trauma or tooth extraction, restoring the tissue architecture is challenging. Historically, the technique of guided tissue regeneration (GTR) was developed to place a barrier membrane that blocks fast-growing soft-tissue cells and gives slower bone or ligament cells time and space to repopulate a defect.⁵ Over

time, guided bone regeneration (GBR) extended this concept to bone defects, applying membranes plus bone-grafting materials.⁵

In the early days, membranes were either non-resorbable (requiring removal) or simple resorbable with limited bioactivity, and graft materials were primarily autografts, allografts or xenografts chosen for osteoconduction or osteoinduction.⁶ However, limitations such as donor-site morbidity (autograft), variability (allograft), limited volume, unpredictable resorption rates, and infection risk spurred research toward synthetic and composite substitutes.⁷

Today, the paradigm has shifted: instead of “block soft tissue and fill with bone substitute”, we are seeing materials that actively guide cell behaviour, modulate immune response, stimulate vascularisation, and degrade in tune with tissue formation.¹ Functionalised membranes, ion-doped scaffolds, composite polymers, bioactive ceramics and printing technologies are part of this transformation.² In this article, we review these recent advances divided into sections on membrane technologies, grafting materials, biologics and manufacturing innovations, followed by clinical and translational considerations.



Membrane technologies – from passive barrier to smart interface

Initially, membranes for GTR/GBR served a straightforward mechanical function: maintain space and exclude unwanted cells.⁸ Non-resorbable types (e.g., ePTFE) required a second surgery to remove; resorbables (e.g., collagen) removed that requirement but often lacked mechanical strength or predictable degradation.⁹

Recent advances emphasise multifunctionality. Resorbable membranes are now designed using synthetic polymers (polyglycolic acid, polycaprolactone, PEG), natural polymers (collagen, silk fibroin, chitosan) or hybrids, and tuned for mechanical stability, barrier function, growth-factor delivery and antibacterial behaviour.¹⁰ For example, a review of resorbable membranes details these material categories and their key features: foreign-body reaction, resorption rate, growth factor delivery, mechanical and antibacterial properties.¹⁰

Another key trend is asymmetric or “Janus” membranes: one side geared toward bone/healing, the other toward soft-tissue exclusion or even antibacterial function.² Membranes are also being infused with bioactive glass or calcium-phosphate particles to provide osteoconductivity in addition to barrier function.⁸

Electrospinning, multilayering, and advanced fabrication methods (e.g., UV-curing atelocollagen hydrogels) allow tailoring of microstructure, porosity and degradation.¹¹

The functions of modern membranes are being described more biologically: they promote osteoblast adhesion/proliferation, guide progenitor cell migration, facilitate vascularisation, regulate the immune response, suppress infection, and maintain space.¹² For example, a membrane that releases Zn^{2+} or Sr^{2+} ions can stimulate osteogenesis while also inhibiting osteoclast-driven resorption.¹²

Bone grafting materials – modern toolbox

Grafting materials remain central to GTR/GBR. Autograft remains the “gold standard” because it carries living cells, matrix and signalling molecules but drawbacks include donor-site morbidity, limited quantity and unpredictable resorption.¹³ Allografts and xenografts remove donor morbidity but have issues of slower remodelling, variable integration and cost.¹³

Synthetic grafts and bone-substitute materials have therefore grown in popularity. Traditional synthetics are calcium-phosphate ceramics



(hydroxyapatite, beta-tricalcium phosphate (β -TCP), biphasic calcium phosphates) or calcium-sulfate based.¹⁴ More recently, composites combine these ceramics with polymers or bioactive glass, yielding better control of porosity, mechanical strength and resorption kinetics.¹⁵ For example, a recent review on materials science in bone grafting highlights combinatorial approaches between growth-factors, nanomaterials and 3D-manufactured scaffolds.¹⁶

Bioactive glass (and glass-ceramics) has emerged as a key component: they can release ions (silicon, calcium, phosphate, strontium etc) that stimulate osteogenic cell behaviour and have antibacterial properties.¹⁷ In one review of “biofunctional GBR materials”, the authors discuss how doped ceramics (Zn, Sr, Mg, Cu) and graded biomimetic scaffolds are showing promise especially in alveolar and maxillofacial defects.¹²

Scaffold architecture also matters: hierarchical porosity (macro + micro + nano) improves vascular ingrowth, nutrient diffusion, and osteoblast/osteoclast activity.¹⁸ A recent article on scaffolds for GBR emphasises the importance of biomimetic scaffold design, delivery systems, and fabrication methods to overcome limitations such as low structural

integrity and sub-optimal resorption.¹⁹

Another exciting area: composite injectable hydrogels or moldable graft materials that conform to extraction sockets or irregular defects, reducing invasiveness and improving fit.¹² These technologies are especially useful in dental implantology and ridge preservation.¹⁶

Biologics, cell-based strategies and functionalisation

Adding biologics (growth-factors, platelet concentrates), or incorporating cells (mesenchymal stem cells, endothelial progenitors) into grafting systems elevates osteoconductive scaffolds into osteoinductive/regenerative constructs.¹³ For instance, combining platelet-rich fibrin with grafts improves early vascularisation and healing in the socket.¹⁶ However, cost, complexity, regulatory burdens and variable outcomes still limit widespread use.¹³

Functionalisation of scaffold surfaces with peptides, metal ions, or immunomodulatory agents is another trend. For example, Zn^{2+} and Mg^{2+} influence osteoblast/osteoclast balance; Cu^{2+} and Ta coatings support both osteogenesis and angiogenesis.¹² These “bio-functional” materials attempt to mimic the natural bone microenvironment more closely.



Manufacturing innovations: 3D printing, in-situ fabrication and custom grafts

Manufacturing technology is now enabling patient-specific grafts, complex architectures and even intraoperative fabrication. For example, 3D printing (robocasting, extrusion) of bioactive glass/polymer scaffolds has been demonstrated in preclinical models.¹⁸ A recent review on scaffolds states that 3D-fabrication methods allow precise control of pore size, interconnectivity and mechanical properties.¹⁹

Perhaps most futuristic: a “modified glue gun” device for intraoperative direct printing of synthetic grafts into defects using a low-temperature composite of polymer + hydroxyapatite; this allows surgeon-controlled shaping and includes antibiotics in the scaffold. While still early stage, this kind of on-site fabrication could reshape how grafts are used in complex bone repair.

The combination of imaging (CBCT/CT), digital design, and additive manufacturing allows defect-specific grafts that perfectly fit the anatomy, reduce operative time, and perhaps accelerate healing.¹⁶

Clinical trends, evidence landscape and translational issues

Clinical trials of membranes and graft substitutes are increasing, particularly in dental and maxillofacial contexts. Recent reviews show that new materials are closing the gap with traditional grafts in many indications. For example, the narrative review on alveolar bone grafting and ridge preservation highlights newer injectable bone repair materials, hydrogels and 3D-printed scaffolds improving patient-reported outcomes (pain, satisfaction, recovery) in some studies.¹

Nonetheless, long-term data (5+ years) is still scarce and head-to-head comparative trials between newer synthetic/composite materials and autograft/xenograft are limited.¹² The practical adoption of new materials is influenced by cost, surgeon experience, ease of handling, inventory/storage issues and regulatory clearance.⁴

Material safety remains key: biocompatibility, predictable resorption, infection resistance, mechanical stability, and minimal foreign-body reaction are essential for clinical success.¹⁰ Manufacturing consistency, sterilisation, packaging and logistical aspects are often overlooked in bench papers but determine whether a material becomes commercially viable.⁴

Another translational challenge: many



advanced materials (cells, growth-factors, printed scaffolds) fall into higher regulatory categories (combination products) and are cost-prohibitive for routine use. The “effective complexity” needs justification in improved clinical outcome and cost-effectiveness.³

Conclusion

The field of guided tissue and bone regeneration is undergoing a paradigm shift from passive membranes and inert fillers toward smart, multifunctional regenerative systems that actively orchestrate healing. Membranes now do more than block: they deliver cues, modulate cells and prevent infection. Bone-grafting materials are no longer just space-filling; they provide structural support, biological signaling, and match degradation to tissue formation.

Manufacturing advances (3D printing, intraoperative fabrication) are bringing customisation to the surgeon’s toolkit. However, successful translation depends on demonstrating that these advances improve clinical outcomes, reduce morbidity and cost, and integrate seamlessly into everyday practice. As more long-term trials and real-world data emerge, the promise is for safer, faster and more predictable regeneration not just “fill the hole”, but rebuild functional tissue with fewer compromises. For clinicians and

patients alike, the next generation of GTR/GBR holds real hope.

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Review Article

TONGUE MALFUNCTIONS: A REVIEW

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Abstract:

The tongue is a highly dynamic muscular organ essential for numerous oral functions, including mastication, swallowing, speech, and taste. Its posture and movement play a crucial role in the growth and alignment of orofacial structures. Tongue malfunctions, which encompass structural, functional, neuromuscular, and acquired disturbances, can significantly affect dentofacial development, leading to issues such as malocclusion, speech disorders, feeding difficulties, and compromised airway function.

This review provides a comprehensive overview of tongue malfunctions, beginning with the embryological origin and anatomical structure of the tongue. The article highlights the normal posture and equilibrium of tongue forces and their influence on dental arches. Various forms of malfunctions such as tongue thrusting, ankyloglossia, macroglossia, glossoptosis, and neuromuscular disorders are described in terms of etiology, classification, clinical features, and diagnostic approaches. The functional impact of these conditions on swallowing, speech, and skeletal growth is explored, with particular emphasis on abnormal tongue posture and inadequate rest positions. Diagnosis involves a thorough clinical evaluation, functional assessment, and imaging when necessary. Management strategies vary depending on the underlying cause and include myofunctional therapy, orthodontic appliances, surgical interventions, and multidisciplinary collaboration.

Early identification and appropriate treatment of tongue malfunctions are essential for promoting optimal orofacial growth, improving orthodontic outcomes, and enhancing long-term stability. By understanding the diverse presentations and implications of tongue malfunctions, clinicians can better address the functional and structural needs of affected individuals, ultimately improving their quality of life and oral health outcomes.

Key words: Tongue malfunction, Tongue thrusting, Ankyloglossia, Malocclusion, Tongue posture.



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Introduction

The tongue is a highly versatile muscular structure capable of performing an extraordinary range of movements within the oral cavity and reflects the oral and systemic health of an individual. Remarkably, even the fastest fingers of a concert pianist cannot rival the speed and agility of the human tongue during speech.¹ Malocclusions caused by tongue dysfunctions become easier to manage once the underlying habit is identified and the abnormal muscular pressure is eliminated.² The term "habits" is often used to describe compensatory or adaptive patterns of movement of the oral muscle mechanisms.³ Uncoordinated tongue function can alter both the maxillary and mandibular arches, ultimately influencing the type and severity of malocclusion. Factors such as the size, resting position, and activity of the tongue significantly impact dental and skeletal development.⁴ The concept of dental equilibrium involves a complex balance among various forces: resting pressures from the lips and tongue, occlusal forces during function, and the eruptive forces

acting within the periodontal ligament. When this equilibrium is disturbed due to habits, anatomical anomalies, or altered muscle functions it may lead to the development of malocclusions.⁵ These disturbances range from mild habits like thumb sucking to more pronounced functional issues such as anterior tongue thrusting, which may cause an open bite with only the posterior molars in contact.⁶ Malfunctions of the tongue can also result from tongue malformations.⁷

Embryology

The development of tongue begins during the fourth and fifth weeks of gestation (Figure 1). This early development plays a crucial role in shaping both the structure and function of the oral cavity.⁸

- **First Pharyngeal Arch:** This arch gives rise to two lateral lingual swellings and a central structure called the tuberculum impar, which eventually fuse to form the anterior two-thirds (oral part) of the tongue.
- **Second Pharyngeal Arch:** Although this arch initially contributes to the tongue's development, its tissue is largely

overgrown by the third arch. It plays a minor and transient role.

- **Third Pharyngeal Arch:** This arch gives rise to the posterior one-third of the tongue (pharyngeal part), contributing to the root and the circumvallate papillae region.
- **Fourth Pharyngeal Arch:** It forms the epiglottis and the extreme posterior part of the tongue, which merges with the third arch structures.

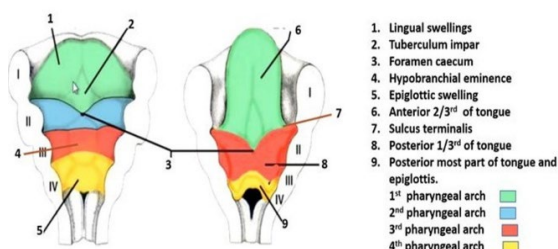


Figure 1: Development of the tongue.

Anatomy of the tongue

The tongue is a muscular organ covered by mucous membrane and papillae called filiform, fungiform, circumvallate, and foliate, that aids in taste and mechanical functions. It is divided into an anterior two-thirds (oral part), which handles taste and food movement, and a posterior one-third (pharyngeal part), which is fixed and contains lingual tonsils for immune defence. Anatomically, it is bordered by the

REGION OF TONGUE	GENERAL SENSATION	TASTE SENSATION
Anterior two-thirds (excluding circumvallate papillae)	Lingual nerve	Chorda tympani (branch of facial nerve)
Circumvallate papillae and Posterior one-third	Glossopharyngeal nerve	Glossopharyngeal nerve
Base/Root of tongue	Internal laryngeal nerve (branch of superior laryngeal, vagus)	Internal laryngeal nerve (branch of superior laryngeal, vagus)

Table 1. Sensory innervation of the tongue.

palate above, floor of the mouth below, incisors in front, oropharynx behind, and the lingual and palatal surfaces of posterior teeth on the sides. Sensory innervation of the tongue, showing the distribution of general and taste sensations in the anterior two-thirds, posterior one-third, and base is given in Table 1.

The tongue comprises eight muscles, four intrinsic (superior longitudinal, inferior longitudinal, transverse, vertical) that shape it, and four extrinsic (genioglossus, hyoglossus, styloglossus, palatoglossus) that move it.⁹ The motor nerve supply and arterial blood supply of both extrinsic and



intrinsic tongue muscles are summarized in Table 2. Dorsal lingual and deep lingual veins that unite to form the lingual vein which drains into internal jugular vein.

MUSCLES	MOTOR NERVE SUPPLY	BLOOD SUPPLY
Genioglossus	Lingual branch of hypoglossal nerve	Sublingual and submental arteries
Hyoglossus	Lingual branch of hypoglossal nerve	Sublingual and submental arteries
Styloglossus	Lingual branch of hypoglossal nerve	Sublingual arteries
Palatoglossus	Vagus nerve	Palatine branches from facial, maxillary and ascending pharyngeal arteries
Intrinsic muscles 1. Superior longitudinal 2. Inferior longitudinal 3. Transverse 4. Vertical	Lingual branch of hypoglossal nerve	Deep lingual branch of lingual artery, branches from facial artery

Table 2. Motor innervation and blood supply of the tongue muscles.

REGION OF TONGUE	LYMPH NODE DRAINAGE	LATERALITY
Tip	Submental Lymph Nodes	Ipsilateral
Rest of anterior 2/3	Submandibular & Deep Cervical Lymph Nodes	Ipsilateral
Posterior 1/3	Deep Cervical Lymph Nodes	Bilateral

Table 3. Lymphatic drainage of the tongue

Normal tongue posture (Equilibrium of the tongue)

In a physiologically normal state, the tongue rests against the anterior portion of the hard palate, with its tip positioned just behind the upper front teeth. This resting posture is essential for proper maxillary arch development and helps maintain the balance of orofacial muscles (Figure 2).

The equilibrium of the tongue is maintained by four primary factors. Intrinsic factors include the natural pressure exerted by the tongue and lips. Extrinsic influences involve habitual forces and the effects of orthodontic appliances. Additionally, the alignment and contact of the teeth contribute through occlusal forces, while the periodontal membrane also plays a role by providing supportive feedback and resistance. Together, these elements help to preserve the stability and function of the tongue within the oral cavity (Figure 3).

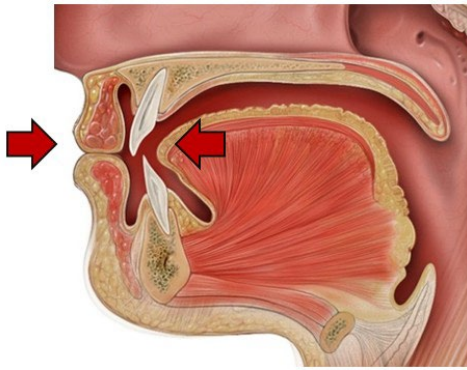


Figure 2. Balance between lingual and perioral pressures maintaining dental arch stability

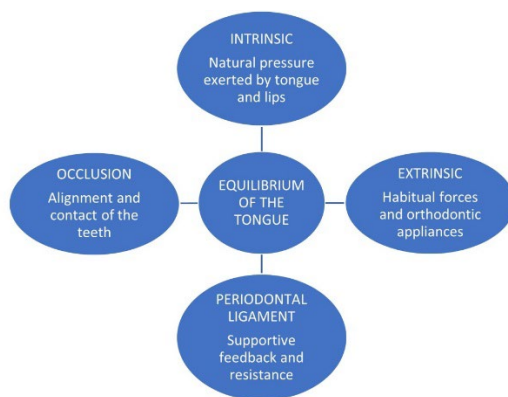


Figure 3: Factors affecting tongue equilibrium

Functions of tongue

The tongue performs a wide range of essential tasks related to oral and systemic health, including feeding, speech, sensory perception, and immune defense.¹⁰

- **Sucking and Swallowing:** Acting like a piston, the tongue generates negative intraoral pressure during sucking, enabling the intake of fluids and soft foods. During swallowing, it propels the food bolus toward the oropharynx, initiating deglutition.
- **Chewing and Salivation:** The tongue works in harmony with the cheeks to

position food between the teeth, ensuring effective mastication. It also presses the food against the palate to help shape it into a cohesive bolus. During this process, the tongue's movements stimulate the sublingual salivary glands, promoting saliva secretion that facilitates lubrication and initiates enzymatic digestion.

- **Taste Perception:** The tongue's surface is lined with taste buds housing sensory cells that detect basic tastes. These receptors not only facilitate flavour recognition but also initiate digestive reflexes, such as increased salivation and gastric secretions.
- **Tactile Sensitivity:** Highly sensitive to touch, especially at the tip, the tongue helps detect food texture and foreign particles like bone fragments. This heightened sensitivity supports oral hygiene by locating food debris post-swallowing.
- **Speech Articulation:** The tongue's flexibility and rapid motor control are critical for articulating phonetic sounds. It shapes airflow to form consonants and vowels, playing a pivotal role in clear speech production. Impaired tongue mobility often results in speech disorders such as lisps.
- **Immune Defense:** The lingual tonsil, situated at the base of the tongue, is a



component of Waldeyer's ring, a group of lymphoid tissues that serve as the first line of immune defense. This structure plays a crucial role in detecting and responding to pathogens that enter through the mouth, thereby contributing to oral and systemic immune protection.

Etiology of tongue malfunctions

- **Genetic and developmental factors:** There is a complexity of factors that might predispose a child toward this habit like an extremely high narrow palatal arch, an imbalance between the number and size of teeth, and the size of the oral cavity.
- **Environmental influences:** Oral habits like thumb sucking, tongue thrusting - This act depresses the tongue and keeps the teeth apart so one can suspect that it also induces malfunctions of the tongue during deglutition.
- **Feeding Practices:** In bottle-fed infants, especially when using long nipples with multiple holes, proper tongue positioning is often hindered. These elongated nipples can extend close to the back of the throat, preventing the infant from pressing the tongue against the palate even if they attempt to do so. Additionally, caregivers often enlarge the nipple holes to ensure free milk flow, which

alters the natural swallowing mechanics.

- **Syndromic Associations:** Tongue malfunctions are commonly associated with several genetic syndromes, including Down syndrome, Beckwith-Wiedemann syndrome, Pierre Robin syndrome, and Prader-Willi syndrome, all of which can contribute to abnormal tongue posture and function.
- **Infections:** Conditions such as upper respiratory tract infections, chronic mouth breathing, tonsillitis, and allergic responses can lead to forward positioning of the tongue. This compensatory adaptation may occur due to pain or reduced oral space and often results in a tongue thrust swallowing pattern. In many cases, it reflects the body's effort to maintain an open and adequate airway.

Clinical features of tongue malfunctions

Intraoral clinical features

- Anterior open bite
- Upper and lower anterior spacings
- Bidental proclination
- Posterior open bite in case of lateral tongue thrusting
- Steep mandibular angle



- Orbicularis oris muscle in a protruding position

Extraoral clinical features

- Usually dolichocephalic face
- Increased lower anterior facial height
- Incompetent lips
- Expressionless face
- Speech problems like sibilant distortions and lisping, etc.
- Abnormal mentalis muscle activity is seen.

Types of tongue malfunctions

Tongue malfunctions can disrupt normal orofacial growth, swallowing, speech, and the stability of orthodontic outcomes. These malfunctions may be functional, structural, neuromuscular or acquired tongue malfunctions.

1. Functional tongue malfunctions

- a. Tongue thrusting
- b. Abnormal swallowing pattern
- c. Inadequate resting posture

2. Structural Tongue Malfunctions

- a. Ankyloglossia (Tongue-Tie)
- b. Macroglossia
- c. Glossoptosis

3. Neuromuscular and Developmental Tongue Disorders

- a. Tongue Hypotonia/Hypertonia
- b. Motor Coordination Disorders
- c. Neuropathies Affecting the Hypoglossal Nerve (CN XII)

4. Acquired Tongue Malfunctions

- a. Iatrogenic
- b. Neurologic disorders
- c. Trauma
- d. Habitual and Environmental Factors

1a) Tongue thrusting

Tulley(1969) defined tongue thrust as the anterior placement of the tongue tip between the dental arches, frequently in contact with the lower lip during swallowing or speech, leading to an interdental tongue position. This pattern is often the continuation of the infantile swallow beyond early childhood, potentially resulting in anterior open bite and forward positioning of the upper front teeth.¹¹

Types of Tongue Thrust

1. Physiologic: This comprises of the normal tongue thrust swallow of infancy
2. Habitual: Learned behaviour, even after the underlying malocclusion or



dental abnormality has been corrected.

3. Functional: Adaptive behaviour developed to achieve an oral seal.
4. Anatomic tongue thrust: Individuals with an enlarged tongue or altered oral structures may adopt a forward tongue posture due to limited space within the oral cavity.

Moyers classification¹²

1. Simple tongue thrust – Teeth remains in contact
2. Complex tongue thrust – Teeth are apart
3. Retained infantile swallow – Persistence of the infantile swallow

Diagnosis

Diagnosis of tongue thrust involves a comprehensive history to rule out factors such as upper respiratory infections, digit-sucking habits, neuromuscular disorders, and atypical swallowing patterns. Clinical examination includes assessment of tongue size, shape, and movement. Observing the tongue during rest, swallowing, and phonation helps identify abnormal patterns. Lateral cephalograms can be used to assess resting tongue posture radiographically. Functional examination includes observing the tongue in a resting mandibular position, during various types of swallowing (conscious, command-induced saliva or water swallowing, and during mastication),

as well as during speech. Evaluation of facial muscles is also important, as normal swallowing does not involve activation of the muscles of facial expression. Any visible contraction or grimace, particularly a line running from the side of the nose to the orbicularis oris with lip protrusion, indicates abnormal swallowing behavior.¹

Management

Management of tongue thrusting typically includes myofunctional therapy, where patients are taught to position the tongue correctly during swallowing. One commonly used technique involves placing the tongue tip on the palatal rugae area and practicing swallowing. Other exercises include the use of sugarless fruit drops or orthodontic elastics to encourage appropriate tongue activity. Specific training methods like the 4S (Spot, Salivate, Squeeze, Swallow) and 2S (Spot and Squeeze) exercises are also effective. Additional activities such as whistling, reciting numbers (especially 60 to 69) and yawning may help reinforce correct tongue function. Orthodontic interventions can assist in habit correction and include devices such as orthodontic trainers with tongue guards, lip bumpers, and labial bows. Appliances like fixed or removable tongue cribs, Nance palatal arches with acrylic buttons, Bluegrass appliances, and oral screens are useful in guiding tongue posture and eliminating abnormal muscle



habits. In some cases, hybrid habit-breaking devices incorporating fixed cribs or racks may be employed as part of a comprehensive orthodontic treatment plan.

1b) Abnormal swallowing pattern

Abnormal swallowing can lead to significant alterations in facial development, including a marked narrowing or collapse of the maxilla. When a complete crossbite is present, the resulting masticatory forces exert unfavourable pressure on the upper jaw, influencing mandibular growth in a negative way. In many cases, children who have not developed a proper swallowing pattern fail to position their tongue against the palate. Over time, this lack of stimulation contributes to a maxillary arch so constricted that the tongue can no longer rest against it naturally. Furthermore, as the mandible grows, the persistent pressure of the tongue between the teeth during repeated episodes of abnormal swallowing can gradually alter the mandibular plane angle, affecting the overall growth pattern and balance of the lower jaw.²

1c) Inadequate resting posture

An improper resting posture of the tongue, such as lying low in the oral cavity or pressing against the teeth, can disturb the balance of forces that maintain proper dental alignment. Ideally, the tongue should rest lightly against the palate with the tip near the incisive papilla. When this balance

is disrupted, it may contribute to malocclusions like open bite, arch constriction, or spacing. Inadequate tongue posture is often linked to habits, airway obstruction, or neuromuscular issues, and requires early intervention to support normal orofacial development.⁵

2a) Ankyloglossia

Ankyloglossia, also known as tongue-tie, is a condition that impairs tongue movement due to a restrictive lingual frenulum.¹³

Classification

According to Coryllos, ankyloglossia can be classified into four types (Figure 4) based on the position and characteristics of the lingual frenulum.¹⁴

Type 1 – Frenulum attaching directly to the tip of the tongue

Type 2 – The attachment is located slightly behind the tip, approximately 2 to 4 mm posterior

Type 3 – Involves a thick, fibrous frenulum connected to the middle of the tongue and the central area of the floor of the mouth; this type is usually tight and less flexible

Type 4 – Characterized by a thick, shiny, and highly inelastic submucosal frenulum, which limits movement at the base of the tongue due to its restrictive nature

Management

Frenotomy is typically advised for infants with ankyloglossia who continue to face breastfeeding challenges despite attempts at conservative management.¹⁵ Early

identification and appropriate management of ankyloglossia are crucial in preventing long-term functional impairments.¹⁶

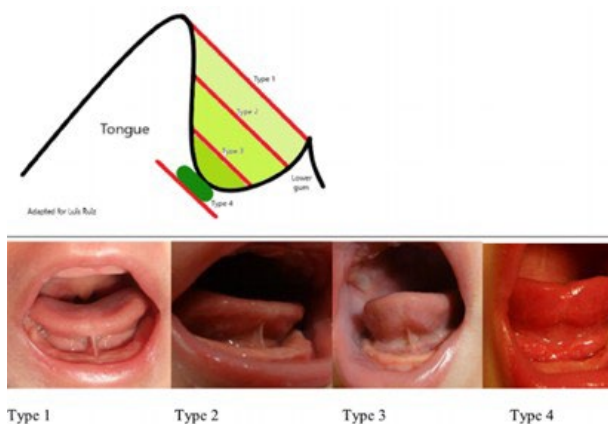


Figure 4: Coryllos types of tongue-tie

2b) **Macroglossia**

Macroglossia refers to an abnormal enlargement of the tongue that may be either true or relative.¹⁷

True macroglossia involves an actual increase in tongue tissue due to muscular hypertrophy, vascular malformations, or infiltration by pathological conditions.

Pseudomacroglossia refers to the apparent enlargement of the tongue secondary to surrounding anatomical or skeletal discrepancies, such as mandibular hypoplasia or maxillary constriction, where the tongue is normal in size but appears large due to lack of space in the oral cavity.

Etiology

Congenital Causes: Tongue abnormalities may be present at birth and are often linked to genetic or developmental syndromes such as Down syndrome or Beckwith–Wiedemann syndrome.

Acquired Causes: These develop later in

life due to various medical conditions, including amyloidosis, hypothyroidism, acromegaly, or the presence of vascular lesions like hemangiomas or lymphangiomas.

Clinical Recognition

Clinical signs include tongue protrusion, crenations on the lateral tongue borders, drooling, speech difficulties, and dentofacial anomalies such as open bite, interdental spacing, and mandibular prognathism. In severe cases, macroglossia may also interfere with airway patency and contribute to obstructive sleep apnea.

Diagnosis

Careful differentiation from pseudomacroglossia and typically involves clinical evaluation, imaging, and occasionally histopathological examination.

Management

Depends on the underlying etiology and the severity of functional or esthetic impairment. Conservative approaches such as monitoring, speech therapy, and orthodontic management are preferred for mild cases, while surgical intervention (e.g., partial glossectomy using wedge or keyhole techniques) is indicated for cases causing significant dysfunction or skeletal deformity. The use of laser therapy, sclerotherapy, or radiotherapy may be considered in specific vascular or infiltrative lesions.



2c) Glossoptosis

Glossoptosis refers to the downward and backward displacement of the base of the tongue, which can result in partial or complete airway obstruction and difficulties with feeding. This condition is frequently observed in infants, especially those with micrognathia or as part of the Pierre Robin sequence, but it may also occur in individuals with generalized hypotonia.¹⁸

Diagnosis

It is typically diagnosed using flexible fiberoptic laryngoscopy, which helps assess the severity by visualizing tongue position relative to the posterior pharyngeal wall.

Management

Guided by severity, include positional therapy (prone/lateral), use of nasopharyngeal or nasogastric tubes, and in severe cases, interventions such as mandibular distraction or tracheostomy. Early identification and individualized treatment can improve respiratory and nutritional outcomes.

3a) Hypotonia/hypertonia (low/high muscle tone)

Hypotonia refers to decreased muscle tone, characterized by reduced resistance to passive stretch and a “floppy” feel without necessarily implying muscle weakness.

Hypertonia refers to increased muscle tone and resistance to passive stretch, often resulting in a stiff or spastic tongue.

Etiology

- Causes include central nervous system (e.g., hypoxic-ischemic injury, genetic syndromes like Down and Prader-Willi) and peripheral or neuromuscular disorders (e.g., SMA, muscular dystrophy)

Clinical Recognition

- **Hypotonia** - Often evident in infants (“floppy baby syndrome”)
- **Hypertonia** - Limit tongue mobility and coordination, leading to abnormal swallowing, and excessive pressure on the dentition, contributing to malocclusions such as deep bite or crossbite

Diagnosis

- Involves a systematic approach: detailed history, physical examination, possibly metabolic/genetic testing and neuroimaging

Management

Treatment largely supportive: physical/occupational/speech therapy, nutritional support, respiratory care. Specific treatment may be required if an underlying cause is identified.

3b) Motor coordination disorders

Motor coordination disorders involve



difficulty in planning, executing, or controlling voluntary movements due to neurological or developmental impairments. They can lead to dysfunctional tongue movements impacting speech, swallowing, and dental arch development. Conditions such as cerebral palsy, developmental coordination disorder (DCD), and neurological injuries may result in poor tongue control, leading to articulation issues, tongue thrusting, or abnormal swallowing patterns.¹⁹

Management

These disorders require early identification and a multidisciplinary management approach involving speech therapy, myofunctional training, and orthodontic care to support optimal oral function and development.

3c) Neuropathies affecting the hypoglossal nerve

The hypoglossal nerve (cranial nerve XII) is responsible for supplying motor innervation to all intrinsic and the majority of extrinsic tongue muscles. Injury to the nerve due to trauma, tumors, infections, or neurodegenerative conditions can result in weakness or paralysis of the tongue on one or both sides.²⁰

Clinical recognition

This may present as tongue deviation toward the affected side, atrophy, fasciculations, and impaired articulation and swallowing. In orthodontics, such

dysfunctions can affect tongue posture and mobility, contributing to malocclusion or relapse after treatment.

Management

Early recognition and neurological evaluation are essential for proper diagnosis and management

4) Acquired tongue malfunctions

Acquired tongue malfunctions are functional impairments of the tongue that develop after birth due to various reasons. Unlike congenital malfunctions, these conditions are not present at birth but result from external or systemic factors.

- a. Iatrogenic Causes:** Post-surgical, especially glossectomy, lingual nerve damage during third molar extractions, or radiation therapy can lead to altered tongue mobility or sensation
- b. Neurological Disorders:** Conditions such as stroke, traumatic brain injury, Parkinson's disease, and multiple sclerosis can disrupt motor control of the tongue, often leading to speech difficulties (dysarthria) and swallowing problems (dysphagia).
- c. Trauma:** Injuries to the oral cavity may damage the muscles or nerves associated with tongue movement, resulting in impaired tongue function.
- d. Habitual and Environmental Factors:** Prolonged non-nutritive sucking, improper oral habits, or



orofacial myofunctional disorders may lead to acquired tongue thrusting or abnormal swallowing patterns.

Clinical recognition

- Speech articulation difficulties
- Swallowing and feeding issues
- Malocclusions (due to abnormal tongue pressure on teeth)
- Altered tongue posture and mobility

Management:

Treatment depends on the underlying cause and may include speech therapy, myofunctional therapy, orthodontic correction, and neurological rehabilitation. A multidisciplinary approach often yields the best outcomes.

Conclusion

Tongue malfunctions can significantly disrupt normal dentofacial development and occlusion. Abnormal tongue posture and function often contribute to malocclusions like anterior open bite, proclination, spacing, crossbite, and arch form discrepancies. The tongue's constant pressure, frequency of contact, and position at rest play a more critical role in tooth position than previously thought, as described by the equilibrium theory. Accurate diagnosis requires careful assessment of tongue size, mobility,

posture, function during swallowing and speech, and associated habits, often aided by lateral cephalograms, speech evaluation, and functional tests. Early identification of tongue dysfunction in growing patients allows for interceptive orthodontics, habit correction, and myofunctional therapy, which can improve treatment stability and reduce relapse risk. A multidisciplinary approach involving orthodontists, speech therapists, pediatricians, and oral surgeons is essential for managing complex tongue-related malfunctions. Addressing the underlying tongue dysfunction alongside orthodontic treatment enhances functional outcomes and long-term stability of occlusal correction.

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Review Article

ARTIFICIAL INTELLIGENCE IN DENTISTRY: AN OVERVIEW

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Abstract:

Artificial intelligence (AI) is increasingly influencing modern dentistry by supporting diagnosis, treatment planning, and clinical decision-making. Advances in machine learning and deep learning, together with the growing use of digital radiography, cone-beam computed tomography, and intraoral scanning, have enabled the application of AI across multiple dental specialties. AI-based systems have demonstrated improved accuracy in radiographic interpretation, caries detection, orthodontic assessment, periodontal evaluation, prosthetic design, and other clinical applications, thereby enhancing efficiency and reducing operator-dependent variability. Despite these advantages, challenges such as high costs, data quality requirements, ethical concerns, and limited practitioner training remain. Artificial intelligence should therefore be regarded as an adjunct rather than a replacement for clinical expertise. With appropriate validation, ethical implementation, and professional training, AI holds significant potential to improve patient care and shape the future of dentistry.

Keywords: Artificial intelligence; Dentistry; Machine learning; Deep learning; Digital dentistry

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Introduction

Artificial intelligence (AI) refers to the ability of computer systems to perform tasks that normally require human intelligence, such as learning, reasoning,

and problem solving. The concept of AI evolved during the mid-20th century, with Alan Turing proposing the idea of machine intelligence and introducing the Turing Test



to evaluate intelligent behaviour in machines.¹ The term “artificial intelligence” was formally introduced by John McCarthy at the Dartmouth Conference in 1956, marking the beginning of AI as a scientific discipline.²

AI integrates several computational techniques, including machine learning (ML), artificial neural networks (ANN), and deep learning (DL).³ These systems enable computers to analyse large volumes of data, recognize patterns, and generate predictive outcomes with minimal human intervention. Recent advances in computing power and digital technologies have facilitated the rapid integration of AI into healthcare, including dentistry.⁴

In dentistry, AI has emerged as a valuable adjunct to clinical decision-making by enhancing diagnostic accuracy, improving treatment planning, and supporting personalized patient care.⁵ This review aims to provide a simplified overview of artificial intelligence, its core concepts, and its applications across various branches of dentistry, highlighting its clinical relevance, advantages, and future potential for dental professionals and students.

Artificial Intelligence and Branches of Dentistry

AI in Oral and Maxillofacial Radiology

AI can be integrated with dental imaging modalities such as intraoral periapical radiographs, panoramic radiographs, and cone-beam computed tomography (CBCT). Machine learning algorithms trained on large image datasets are capable of detecting subtle radiographic changes that may be overlooked during routine interpretation. AI-assisted systems can identify dental caries, periapical lesions, bone loss, fractured roots, and anatomical variations, thereby improving diagnostic reliability and saving clinical time.⁶

Deep learning models, particularly convolutional neural networks (CNNs), have demonstrated diagnostic accuracy comparable to experienced clinicians in identifying periapical pathologies and segmenting dental structures on CBCT images.⁷ Automated image segmentation also assists in volumetric analysis and enhances treatment planning in endodontics and implant dentistry.⁸

AI in Cariology and Endodontics



In cariology, AI has shown promising results in detecting proximal and occlusal caries using digital radiographs and near-infrared transillumination images. Deep learning-based systems can differentiate carious lesions from healthy tooth structures with high diagnostic precision.⁹ In endodontics, AI algorithms assist in determining working length, identifying accessory canals, and locating the apical foramen, thereby supporting clinicians in achieving more predictable treatment outcomes.¹⁰

AI in Orthodontics

Orthodontics has benefited considerably from AI-based image analysis and predictive modelling. AI software is used for automated cephalometric landmark identification, diagnosis, and treatment planning.¹¹ Machine learning models analyse facial profiles, dental arch patterns, and skeletal relationships to assist in extraction decisions and treatment outcome prediction, reducing manual errors and improving efficiency.¹²

AI in Oral and Maxillofacial Surgery

In oral and maxillofacial surgery, AI supports surgical planning through virtual simulations and outcome prediction. Deep learning algorithms have been applied to predict postoperative facial swelling

following impacted third molar extraction and to assist in designing surgical guides.¹³ AI also contributes to the early detection of oral potentially malignant disorders by analysing clinical and histopathological data, facilitating timely intervention and improved prognosis.¹⁴

AI in Periodontology

Periodontal diseases are highly prevalent and require early diagnosis to prevent disease progression. AI-based diagnostic systems using artificial neural networks, support vector machines, and decision trees have been employed to classify periodontal conditions based on clinical and radiographic data.¹⁵ Deep learning models can also analyse oral photographs to differentiate healthy gingival tissues from inflamed tissues, supporting early diagnosis and treatment planning.¹⁶

AI in Prosthodontics and Implant Dentistry

In prosthodontics, AI assists in digital impression analysis, denture design, tooth shade selection, and restoration planning.¹⁷ AI-enabled systems enhance the precision of prosthesis fabrication while reducing human error. In implant dentistry, AI supports optimal implant placement by analysing bone quality, anatomical landmarks, and prosthetic requirements. AI-based analysis of dental radiographs has



also shown potential in detecting low bone mineral density and osteoporosis, which is clinically relevant for implant treatment planning.^{18,19}

AI in Dental Public Health

Artificial intelligence has applications in dental public health by supporting disease surveillance, risk assessment, and community-based oral health programs. AI-driven systems can analyse population-level data to predict caries prevalence and identify high-risk groups, enabling targeted preventive strategies and efficient allocation of resources.²⁰

AI in Paediatric Dentistry

In paediatric dentistry, AI aids in growth assessment, diagnosis, and preventive care planning. Digital technologies combined with augmented reality tools help educate children and caregivers about oral health conditions and treatment procedures. AI also assists in managing variability in growth-related data, thereby supporting accurate diagnosis and long-term monitoring.²¹

Challenges and Limitations of

Ai In Dentistry

Despite its advantages, the application of AI in dentistry faces several challenges. High costs associated with advanced equipment and software limit widespread adoption. AI systems require large, high-quality datasets for training, and inaccuracies in data may affect performance. Ethical concerns related to data privacy, security, and algorithm transparency remain significant. Moreover, AI cannot replicate clinical judgment, empathy, or contextual decision-making. Therefore, AI should be regarded as a supportive tool rather than a replacement for dental professionals.²²

Conclusion

Artificial intelligence is rapidly transforming modern dentistry by enhancing diagnostic accuracy, treatment planning, and clinical efficiency. Its applications span multiple dental specialties, including radiology, endodontics, orthodontics, periodontology, prosthodontics, and public health dentistry. While AI offers substantial benefits, careful and ethical implementation is essential to address its limitations.

For dental students and clinicians, gaining a basic understanding of artificial



intelligence is increasingly important, as these technologies are expected to become integral components of future dental practice. With appropriate training and responsible integration, AI has the potential to significantly improve patient care while complementing the expertise and judgment of dental professionals.

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Review Article

MANDIBULAR CONDYLAR FRACTURE: NAVIGATING THE TREATMENT DILEMMA

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Abstract

Background: Condylar fractures of the mandible represent a significant clinical challenge in oral and maxillofacial surgery, particularly when considering pediatric patients. These fractures, due to their unique location and involvement with the temporomandibular joint (TMJ), pose a dilemma regarding optimal management strategies. This literature review explores the various treatment approaches, including conservative and surgical options, the potential complications, and the long-term outcomes associated with condylar fractures in both adult and pediatric populations. A comprehensive analysis of recent research highlights the evolving paradigms in the management of condylar fractures, underscoring the need for individualized treatment based on fracture type, patient age, and characteristics.

Key words: Condylar Fracture, Pediatric Mandibular Fractures, Temporomandibular Joint, Conservative Management, Surgical Management, Open Reduction and Internal Fixation, Complications, Functional Outcomes

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Introduction

Condylar fractures are one of the most common types of mandibular condylar fractures and it accounts 25–50% of all

mandibular fractures because of its relatively thin neck compared to the mandible, and its location against relatively strong cranial base which makes condyle prone to fracture during traumatic



load transfer, and muscle pull especially by lateral pterygoid.¹

Condylar fractures are often resulting from trauma such as road traffic accidents, falls, or physical assaults.²

The management of these fractures is controversial due to the complex anatomy of the condyle and the potential for long-term functional complications, including temporomandibular joint dysfunction and malocclusion.^{3,4} This review aims to assess current literature on the treatment and management of condylar fractures, with an emphasis on the evolving clinical approaches, the inclusion of pediatric patients, and the associated outcomes.

Classification and Epidemiology

Condylar fractures are typically divided into two main categories: intracapsular and extracapsular. Intracapsular fractures involve the temporomandibular joint (TMJ), while extracapsular fractures occur outside the joint capsule.¹ Intracapsular fractures are often more difficult to treat due to their close relationship with the TMJ and the risk of complications such as ankylosis or joint dysfunction. The incidence of condylar fractures is higher in young adults, particularly in males, with a significant number of fractures occurring

as a result of road traffic accidents.²

Pediatric Mandibular Condyle Fractures

Pediatric mandibular condyle fractures present unique challenges in comparison to adult fractures. In children, the condylar process is still undergoing development, which means that fractures may affect the growth and development of the mandible and temporomandibular joint (TMJ). The treatment of pediatric condylar fractures requires careful consideration of both fracture stabilization and the preservation of normal growth.³

The incidence of condylar fractures in pediatric patients is often due to falls, sports injuries, or physical abuse. Conservative management, such as observation, soft diet, and physiotherapy, is often the first-line treatment for non-displaced fractures or fractures with minimal displacement. However, displaced fractures or those affecting the TMJ may require surgical intervention.⁴ A study by Kinsella et al. (2018) emphasized that while conservative approaches are effective in many pediatric cases, surgery might be necessary in cases of significant displacement or those that risk impaired growth.⁴



In pediatric patients, the risk of complications such as mandibular growth disturbance and facial asymmetry is particularly concerning.³ These complications often arise from improper alignment or poor fracture healing. Hence, the treatment goals in children focus not only on fracture healing but also on preserving the potential for normal jaw growth.⁷ Pediatric condylar fractures are often treated with either closed reduction techniques or minimally invasive surgical methods, such as open reduction with internal fixation (ORIF), to avoid disturbing the growing condyle.¹

Treatment Approaches: Conservative vs. Surgical Management

Treatments of mandibular condyle fractures depend on different factors:

1. If the fractures are incomplete or complete;
2. Displacement of fragments and position of the condyle;
3. Malocclusion, and
4. Edentulous patient.

Historically, condylar fractures were primarily treated conservatively, using methods such as intermaxillary fixation

(IMF) or splints.¹ Conservative treatment is typically reserved for non-displaced or minimally displaced fractures. However, the advent of surgical options has shifted treatment paradigms, especially for displaced fractures or those causing functional impairment.² Surgical options, such as open reduction and internal fixation (ORIF), offer more predictable outcomes in terms of fracture alignment and functional restoration. The dilemma between conservative and surgical management depends on factors such as fracture displacement, associated injuries, and the patient's age and overall health.⁴

In a recent study, Tanaka et al. concluded that while conservative treatment may be appropriate for stable, non-displaced fractures, surgical intervention is recommended for fractures with significant displacement or those causing occlusal disturbance.⁴ The decision to opt for surgery is influenced by the risk of joint complications and the need for long-term functional restoration.

According to Choi and yoo, pre-auricular, sub-mandibular and retro-mandibular approaches are not useful when operating on high condylar neck fractures because the access for accurate placement of the plates and screws is limited.³ The extended pre-auricular incision reported by hammer



et al. provided sufficient exposure of the condylar neck and the entire ascending ramus, but detaching the masseter muscle from the zygomatic arch entails considerable damage.⁴

In the last few decades, many different approaches have been proposed, particularly for condylar neck fractures, to treat cases in which closed treatments (e.g., intermaxillary fixation, mandi-fix, anchor screws, etc.) appear unsuitable.^{5,6} Among these surgical approaches, we cannot identify an “ideal” technique. In fact, The facelift-transparotid approach, the trans-masseteric antero-parotid approach and the transparotid transcutaneous approach are valid if performed by experienced surgeons, but, in our opinion, these methods do not prove much safer than a transparotid approach with little parotid tissue removal, which provides excellent exposure of the facial nerve and fracture site in all cases.

Ramaraj et al. (2020) compared the transparotid and anteroparotid transmasseteric approaches and found that the anteroparotid approach resulted in better outcomes, with reduced risk of complications such as facial nerve weakness and parotid fistula.²

Transparotid Transcutaneous Approach

- **Technique and Procedural Steps:** This approach involves a preauricular incision extending into the parotid gland to access the condylar fracture site.¹
- **Advantages and Limitations:** It provides direct access to the condyle but poses risks to the facial nerve and may result in salivary complications.¹

Anteroparotid Transmasseteric approach

- incision was marked slightly curved and below as compared to transparotid, 1 cm below earlobe till gonial angle parallel to the posterior border of the mandible and then curved approximately 2 cm anteriorly below the inferior border of the mandible.²

Retromandibular Approach: Transparotid vs. Anteroparotid Transmasseteric

- **Comparative Study on Surgical Time and Outcomes:** A study by Ramaraj et al. compared these two variations, finding that the anteroparotid transmasseteric approach had shorter surgical times and fewer complications.²



Figure 1: Retromandibular transmasseteric approach



Figure 2: Incision for retromandibular transparotid approach

Surgical Management: Open Reduction and Internal Fixation

The management of condylar fractures has long been debated, primarily oscillating

between closed reduction and open reduction with internal fixation (ORIF).

Indications for Closed Reduction

Closed reduction is often indicated for:

- Nondisplaced or minimally displaced fractures
- Pediatric patients, due to growth considerations
- Patients with medical contraindications to surgery

This approach aims to allow natural healing while minimizing surgical risks.⁷ For closed reduction, intermaxillary fixation is conducted using arch bar and wire, followed by maintaining of the fixation of the maxilla and mandible for 2 to 4 weeks.⁷ After achieving stable union of the fractured site, a wire for intermaxillary fixation is removed. Then, normal occlusion is induced after fixation using rubber, and soft diet is maintained for 2 weeks. Functional therapy that consists of passive mandibular movement exercise and mouth opening exercise is conducted and then clinical outcomes are observed.⁷ For mouth opening exercise, the physician holds the molar and mandibular border of the fracture side after standing behind the patient, and induces normal occlusion and normal mandibular



movement by traction. At the same time, the patient opens his/her mouth for him/herself, and applies counter-force using hands to avoid mandibular deviation. Initial intermaxillary fixation period varies, intermaxillary fixation in intracapsular fracture patients aged less than 5 years for 2 weeks, in those aged 5 years or higher for 4 weeks, and in extracapsular fracture patients aged less than 8 years for 2 weeks.⁷

Indications for Open Reduction

ORIF is considered in cases of:

- Displaced fractures causing malocclusion
- Bilateral condylar fractures with an anterior open bite
- Fractures with mechanical block to mandibular movement

This method facilitates direct visualization and precise anatomical reduction.⁸

Comparative Outcomes and Patient Selection Criteria

Studies have shown that ORIF can lead to better functional outcomes in terms of mandibular mobility and occlusion.^{8,9} However, it carries risks such as facial nerve injury and scarring. Conversely, closed reduction avoids surgical risks but

may result in compromised functional outcomes in certain cases. Patient-specific factors, including age, fracture type, and overall health, should guide the treatment choice.⁷

Intracapsular and extracapsular condylar fractures

Not all mandibular fractures require surgery; in fact, a large number can be treated non-surgically, with pain-killers, physiotherapy or intermaxillary fixation under local anaesthesia in the outpatient department. It is unanimously agreed that open reduction is absolutely contraindicated for intracapsular fractures, being considered still experimental.^{5,6}

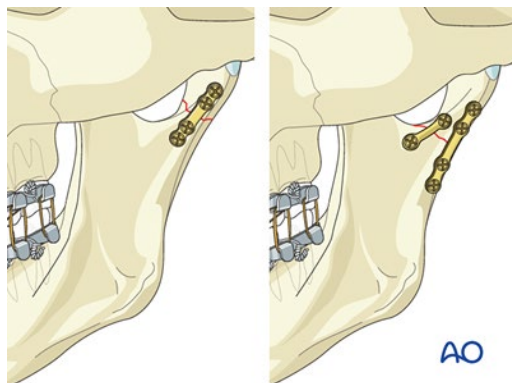
Different plating techniques in condylar fracture

3D Delta plates have been designed to adapt to and neutralize strain during ORIF of condylar fractures and have the advantage of being smaller in size.⁸

Ganguly et al. stated that compared to conventional mini plates, delta plates provide better results in terms of operating time, mouth opening, and biting

efficiency. The geometry and the design of the plate provide better stability and it allows the implant to easily accommodate the anatomy of the fracture, resulting in minimal risks and complications intraoperatively. A week of immobilization was sufficient to allow for early rehabilitation and functional loading.⁸

This plating system is associated with very few complications but it also has some disadvantages such as the length of the delta plate and the adaptability with the curvature in the condylar neck region.⁸



2.0 mm Delta Bone Plate



The use of plate and screw fixation in the management of mandibular fractures is a performance-proven technique, as patients resume normal function of the mandible immediately after surgery. The two mini-plates applied at the posterior and anterior border of the condylar neck seem to have the beneficial effect of restoring the tension and compression trajectories.⁹ Sargent and Green reported that the subcondylar fractures were approached via a retro-mandibular incision and were fixed with two mini-plates.⁹ Hammer et al. reported, based on their clinical observation, that a high failure rate was observed with a single miniplate. In addition, they reported that adequate stability could be obtained with either a single mini-dynamic compression plate or a single 2.4 mm plate.⁹

Complications and Long-Term Outcomes

Complications associated with condylar fractures, particularly those treated surgically, include TMJ dysfunction, malocclusion, and the formation of fibrous adhesions within the joint.^{5,7} Murphy et al. highlighted that while surgical treatment improves occlusal alignment and reduces the risk of long-term pain, complications such as temporomandibular disorders



(TMD) remain a concern. The long-term functional outcomes depend largely on the timing of treatment and the preservation of joint function.

Studies have shown that condylar neck fractures are often associated with ankylosis, and the common finding of a medial projection of bone in TMJ ankylosis may be the remnants of a medially dislocated fractured condyloid process.⁷

A study by Kaus et al. found that patients treated surgically reported better outcomes in terms of jaw mobility and masticatory function compared to those managed conservatively.⁶ However, conservative management is often associated with a higher rate of joint stiffness and malocclusion.⁷

Technological Advances in Management

The novel minimally invasive technique involves intraoral access and fracture fragment realignment using a periosteal elevator, a molar occlusal splint, and intermaxillary fixation after intraoperative radiologic imaging confirmation of condyle reposition.⁹

Intraoral mini-invasive technique (IMIT) is a surgical approach developed from the combined minimally invasive technique [COMIT] and the Aksoyler technique, which aims to overcome the limitations and complications of ORIF for the treatment of extracapsular condylar fractures.⁹

Conclusion

The management of condylar fractures remains a dilemma in oral and maxillofacial surgery, with ongoing debate over the optimal approach.⁹ While conservative treatment may suffice for stable, non-displaced fractures, surgical intervention is often required for displaced fractures or those causing significant functional impairment. Advances in imaging technologies, surgical techniques, and materials have improved the accuracy of diagnosis and treatment planning, offering better outcomes in terms of fracture healing and functional recovery.⁸

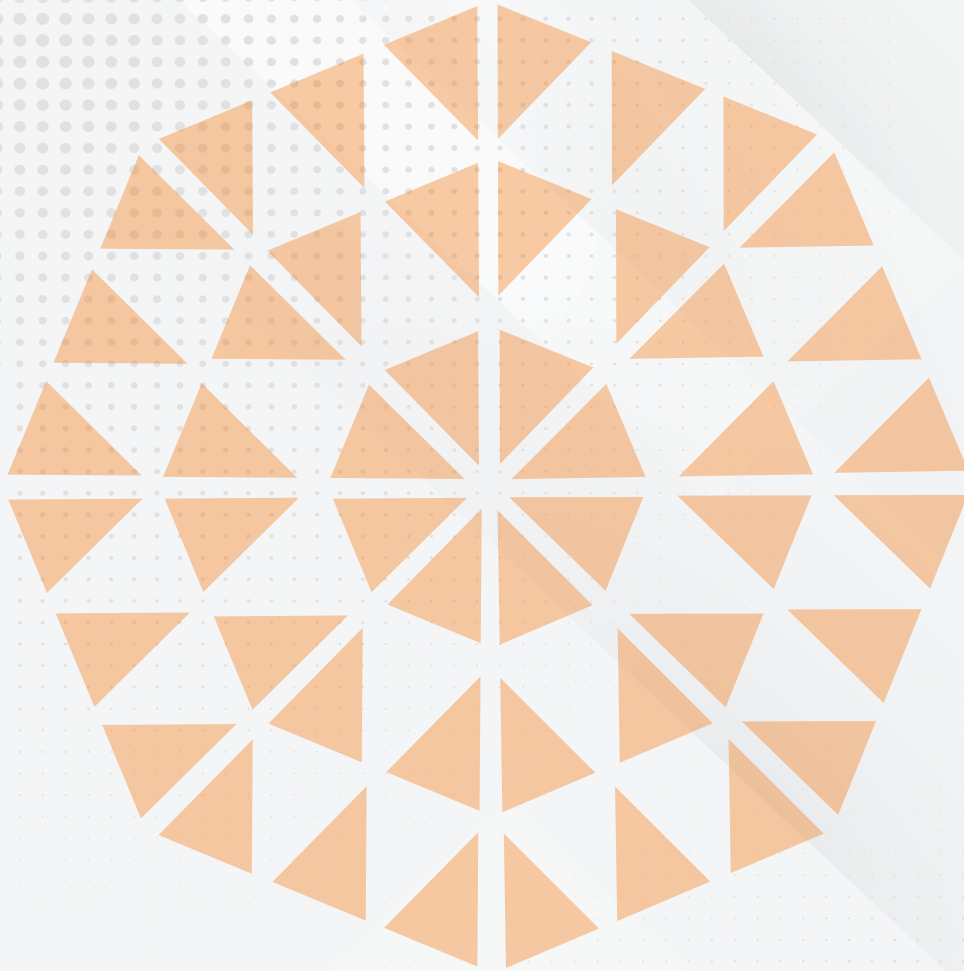
Pediatric condylar fractures present unique challenges, particularly in terms of preserving mandibular growth and preventing long-term developmental issues. However, the risk of complications such as TMJ dysfunction and long-term pain requires careful consideration of treatment options.^{5,6,7} Ultimately,



individualized treatment plans based on fracture characteristics, patient age, and other factors are essential to achieving the best functional and aesthetic outcomes.⁹

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