World Journal of Pharmaceutical Science and Research

www.wjpsronline.com

Review Article

ISSN: 2583-6579
SJIF Impact Factor: 6.916
Year - 2026
Volume: 5; Issue: 6
Page: 989-1007

BIOFILM-ASSOCIATED ORAL DISEASES: ADVANCES IN DIAGNOSIS AND CHALLENGES IN TREATMENT IN AYURVEDA AND MODERN MEDICAL SCIENCES - REVIEW ARTICLE

Prof. Dr. Santoshkumar M. Arjunagi*, M. S. Shalya Tantra

Professor & Head, Department of Shalya Tantra Goel Ayurvedic Medical College & Hospital, Lucknow, Uttar Pradesh, India.

Article Received: 27 April 2026 | | Article Revised: 17 May 2026 | | Article Accepted: 07 June 2026

***Corresponding Author: Professor Dr. Santoshkumar M. Arjunagi**
Professor & Head, Department of Shalya Tantra Goel Ayurvedic Medical College & Hospital, Lucknow, Uttar Pradesh, India.
DOI: https://doi.org/10.5281/zenodo.20689161

How to cite this Article: Professor Dr. Santoshkumar M. Arjunagi, M. S. Shalya Tantra (2026) BIOFILM-ASSOCIATED ORAL DISEASES: ADVANCES IN DIAGNOSIS AND CHALLENGES IN TREATMENT IN AYURVEDA AND MODERN MEDICAL SCIENCES- REVIEW ARTICLE. World Journal of Pharmaceutical Science and Research, 5(6), 989-1007.

ABSTRACT

Oral biofilms are structured microbial communities embedded in a self-produced extracellular matrix that adhere to oral surfaces such as teeth, gingiva, tongue, and dental restorations. Biofilm formation plays a central role in the pathogenesis of several oral diseases including dental caries, gingivitis, periodontitis, peri-implantitis, and oral candidiasis. Despite advances in antimicrobial therapy and dental technologies, biofilm-associated infections remain difficult to eradicate because of their resistance to antibiotics, host immune responses, and environmental stress. Modern medical science has introduced advanced diagnostic methods including molecular techniques, fluorescence imaging, confocal microscopy, and salivary biomarkers for early detection of oral biofilms. Simultaneously, Ayurveda describes conditions comparable to oral diseases under *Mukharoga* and emphasizes preventive oral hygiene practices, herbal formulations, and local therapeutic procedures. Ayurvedic drugs possessing antimicrobial, anti-inflammatory, antioxidant, and wound-healing properties may provide supportive benefits in biofilm management. The present review highlights the role of oral biofilms in disease progression, recent diagnostic advancements, challenges in treatment, and the integrated approach of Ayurveda and modern medicine for effective management.

KEYWORDS: Oral biofilm, Dental plaque, Periodontitis, *Mukharoga*, Ayurveda, Oral microbiome, Biofilm resistance, Herbal medicine.

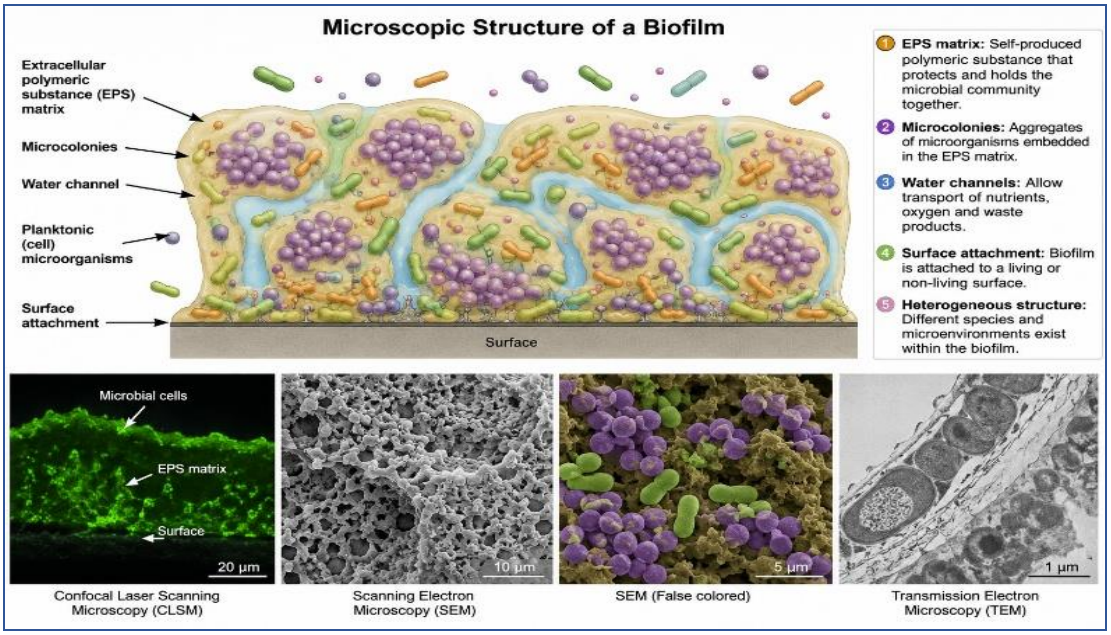
INTRODUCTION

The oral cavity harbours one of the most diverse microbial ecosystems in the human body. More than 700 microbial species including bacteria, fungi, and viruses coexist within the oral environment. These microorganisms organize into structured communities known as biofilms, which are attached to oral surfaces and surrounded by an extracellular polymeric matrix. Dental plaque is considered the most common example of oral biofilm and plays a major role in the development of oral diseases.[1,2]

Biofilm-associated oral diseases are among the most prevalent chronic diseases worldwide. Dental caries and periodontal diseases significantly affect oral health, quality of life, nutrition, and systemic health. Oral biofilms exhibit increased resistance to antibiotics and host immune mechanisms, making treatment difficult and often leading to chronic infection and recurrence.[3,4] Recent research has demonstrated a close relationship between oral biofilms and systemic conditions such as diabetes mellitus, cardiovascular diseases, respiratory infections, and rheumatoid arthritis.[29]

Ayurveda, the traditional system of Indian medicine, has described oral diseases under the category of *Mukharoga*. Classical Ayurvedic texts explain the importance of oral hygiene procedures such as *Dantadhavana*, *Gandusha*, *Kavala*, and herbal therapies for maintaining oral health. The integration of Ayurvedic principles with modern diagnostic and therapeutic approaches may offer a holistic strategy for managing biofilm-associated oral diseases.

Photo 1: Oral Biofilm: Concept and Formation.



A biofilm is a structured microbial community enclosed in a self-produced extracellular polymeric substance (EPS) attached to a living or non-living surface. In the oral cavity, biofilm formation occurs in sequential stages:

1. Formation of acquired pellicle on tooth surface.
2. Initial bacterial adhesion by pioneer microorganisms.
3. Colonization and co-aggregation of secondary bacteria.
4. Biofilm maturation with extracellular matrix production.
5. Dispersion of microorganisms to new sites.

The extracellular matrix consists of polysaccharides, proteins, lipids, extracellular DNA, and water.[4] This matrix protects microorganisms from antibiotics, salivary defence mechanisms, and environmental stress. Common microorganisms associated with oral biofilms include *Streptococcus mutans*, *Porphyromonas gingivalis*, *Actinomyces*, *Fusobacterium nucleatum*, *Candida albicans*, and *Treponema denticola*.[5,10]

Biofilm-Associated Oral Diseases

Dental Caries

Dental caries is a multifactorial infectious disease resulting from acid production by cariogenic bacteria within dental biofilms. *Streptococcus mutans* and *Lactobacillus* species metabolize dietary carbohydrates to produce acids that demineralize tooth enamel. Biofilm maturation and acidic microenvironment contribute to disease progression.[6,15]

Gingivitis

Gingivitis is characterized by inflammation of gingival tissues due to plaque accumulation. Clinical manifestations include gingival redness, swelling, bleeding, and discomfort. If untreated, gingivitis may progress to periodontitis.[8]

Periodontitis

Periodontitis is a chronic inflammatory disease associated with destruction of periodontal tissues and alveolar bone. Gram-negative anaerobic bacteria such as *Porphyromonas gingivalis* and *Treponema denticola* are commonly implicated. Biofilm-induced inflammation triggers host immune responses leading to tissue destruction and tooth loss.[8,9]

Peri-Implantitis

Biofilms can also colonize dental implants, leading to peri-implant mucositis and peri-implantitis. The rough surface of implants favours microbial adhesion and chronic inflammation around implants.

Oral Candidiasis

Fungal biofilms formed by *Candida albicans* are associated with oral candidiasis, especially in immunocompromised individuals and denture wearers. Candida biofilms show significant resistance to antifungal drugs.[14]

Endodontic Infections

Persistent root canal infections are often associated with biofilms formed by *Enterococcus faecalis* and other anaerobic bacteria.[13] These biofilms resist conventional irrigation and antimicrobial treatment.

Pathogenesis of Oral Biofilms

Oral biofilm pathogenesis involves microbial interactions, environmental factors, and host immune responses. The imbalance between commensal and pathogenic microorganisms leads to dysbiosis. Frequent carbohydrate intake, poor oral hygiene, smoking, stress, diabetes mellitus, and xerostomia favour pathogenic biofilm development.

Biofilm microorganisms communicate through quorum sensing, a signalling mechanism regulating virulence, antibiotic resistance, and biofilm maturation.[10,11] The extracellular matrix limits penetration of antimicrobial agents and protects microorganisms from phagocytosis. Chronic inflammation induced by biofilms contributes to connective tissue destruction, alveolar bone loss, and delayed wound healing.

Advances in Diagnosis of Oral Biofilms

Clinical Examination

Traditional diagnostic methods include plaque index, gingival index, periodontal probing, bleeding on probing, radiographic examination, and microbial culture studies.

Molecular Diagnostic Techniques

Polymerase chain reaction (PCR), quantitative PCR, DNA-DNA hybridization, and next-generation sequencing have improved identification of oral pathogens and microbial diversity.[10,12]

Salivary Biomarkers

Saliva contains inflammatory mediators, enzymes, proteins, and microbial products useful for diagnosis of oral diseases. Biomarkers such as interleukins, matrix metalloproteinases, C-reactive protein, and microbial DNA are useful in assessing disease activity.

Fluorescence and Imaging Techniques

Quantitative light-induced fluorescence, fluorescence spectroscopy, optical coherence tomography, and confocal laser scanning microscopy help visualize biofilm structure and activity.

Artificial Intelligence and Digital Dentistry

Artificial intelligence-based tools and digital imaging technologies are increasingly used for early diagnosis, risk assessment, and treatment planning in periodontal and cariogenic diseases.

Challenges in Treatment of Oral Biofilms

Antimicrobial Resistance

One of the greatest challenges in the management of oral biofilms is their remarkable resistance to antimicrobial agents. Biofilm-associated microorganisms can exhibit antibiotic resistance levels up to 1000 times greater than their free-floating (planktonic) counterparts. This enhanced resistance occurs because the extracellular polymeric substance (EPS) matrix surrounding the biofilm acts as a protective barrier, limiting the penetration of antimicrobial agents into deeper layers of the biofilm. In addition, microorganisms within biofilms often exhibit altered metabolic activity and slow growth rates, reducing the effectiveness of antibiotics that target actively dividing cells. Genetic exchange among microorganisms inside the biofilm also contributes to the spread of resistance genes, making eradication increasingly difficult. These factors collectively reduce the clinical effectiveness of conventional antibiotic therapy in oral infections such as periodontitis, peri-implantitis, and dental caries.[3,4,11,14]

Recurrence and Chronicity

Recurrence of oral biofilm-associated diseases is another major therapeutic challenge. Even after thorough mechanical debridement and antimicrobial treatment, residual microorganisms may remain attached to tooth surfaces, gingival tissues, or periodontal pockets. These surviving microorganisms can rapidly recolonize and re-establish mature biofilms, leading to chronic and recurrent infections. The persistent nature of oral biofilms contributes to repeated episodes of gingival inflammation, periodontal destruction, and dental caries. Moreover, inadequate oral hygiene practices, poor patient compliance, and unfavourable oral environmental conditions further promote recurrence.

Chronic biofilm-associated infections often require repeated professional interventions, increasing both treatment complexity and healthcare costs.[3,11,13,15]

Complex Microbial Interactions

Oral biofilms are composed of highly organized multispecies microbial communities involving bacteria, fungi, and occasionally viruses. These microorganisms interact synergistically through coaggregation, metabolic cooperation, quorum sensing, and nutrient sharing. Such interactions enhance microbial survival, virulence, and adaptability within the oral cavity. Pathogenic species may support one another by modifying the local environment, neutralizing antimicrobial agents, or evading host immune responses. Because multiple microorganisms contribute collectively to disease progression, targeting a single pathogen often fails to eliminate the entire biofilm. This microbial complexity makes the development of effective targeted therapies extremely difficult and necessitates comprehensive treatment strategies addressing the entire microbial ecosystem.[1,2,5,10,12]

Host Factors

Host-related factors significantly influence the progression and treatment outcomes of oral biofilm-associated diseases.

Systemic conditions such as diabetes mellitus impair neutrophil function, collagen synthesis, and wound healing, thereby increasing susceptibility to periodontal infections. Immunosuppressive disorders and medications reduce host defence mechanisms, facilitating persistent microbial colonization. Smoking adversely affects gingival blood circulation, immune cell activity, and tissue regeneration, resulting in delayed healing and poor periodontal response.

Nutritional deficiencies and psychological stress can further compromise immune function and inflammatory regulation. These host factors not only increase the severity of oral biofilm infections but also reduce the effectiveness of therapeutic interventions, making disease management more challenging.[7,8,9,10,29]

Limited Penetration of Drugs

The extracellular matrix of oral biofilms acts as a major physical and chemical barrier that restricts the diffusion of antimicrobial agents into deeper biofilm layers. Components of the matrix, including polysaccharides, proteins, extracellular DNA, and water channels, can bind or inactivate antimicrobial molecules before they reach target microorganisms. Furthermore, bacteria located in deeper regions of the biofilm often exist in dormant or slow-growing states, reducing their susceptibility to antibiotics. As a result, therapeutic drug concentrations achieved in surrounding tissues may not effectively eliminate microorganisms embedded within the biofilm structure. This limited penetration significantly reduces the success of conventional pharmacological therapies and contributes to persistent infections.[4,11,14,30]

MODERN MANAGEMENT OF ORAL BIOFILM-ASSOCIATED DISEASES

Mechanical Plaque Control

Mechanical plaque control remains the cornerstone of prevention and treatment of oral biofilm-associated diseases.

Procedures such as tooth brushing, interdental flossing, professional scaling, and root planning physically disrupt and remove biofilms from tooth and periodontal surfaces. Regular mechanical cleaning reduces microbial load, prevents maturation of pathogenic biofilms, and minimizes inflammation of gingival tissues. Scaling and root planning are particularly effective in periodontal therapy because they eliminate subgingival plaque and calculus deposits, thereby

promoting periodontal healing. Long-term success of mechanical plaque control depends greatly on patient compliance and maintenance of proper oral hygiene practices.[15,16]

Chemical Plaque Control

Chemical plaque control agents are widely used as adjuncts to mechanical therapy in the management of oral biofilms.

Chlorhexidine mouthwash is considered the gold standard due to its broad-spectrum antimicrobial activity and substantivity within the oral cavity. Other commonly used agents include triclosan, cetylpyridinium chloride, fluoride preparations, and essential oil-containing mouthwashes. These agents help reduce bacterial colonization, inhibit plaque accumulation, and control gingival inflammation. Fluoride additionally enhances enamel remineralization and prevents dental caries. Although chemical agents improve biofilm control, prolonged use may lead to adverse effects such as tooth staining, altered taste sensation, and mucosal irritation.[18]

Antibiotic Therapy

Systemic and local antibiotic therapies are often indicated in severe periodontal infections and aggressive forms of periodontitis. Commonly used antibiotics include metronidazole, amoxicillin, doxycycline, and minocycline. These antibiotics target anaerobic and Gram-negative periodontal pathogens responsible for tissue destruction. Local drug delivery systems such as doxycycline gels and minocycline microspheres provide sustained antimicrobial concentrations directly within periodontal pockets while minimizing systemic side effects. However, indiscriminate antibiotic use may contribute to antimicrobial resistance and disruption of normal oral microbiota. Therefore, antibiotics should be used judiciously and preferably as adjuncts to mechanical debridement rather than as standalone therapy.[17]

Photodynamic Therapy

Photodynamic therapy (PDT) has emerged as a promising minimally invasive approach for oral biofilm management.

In this technique, photosensitizing agents are activated by specific wavelengths of light, generating reactive oxygen species that destroy microbial cells. PDT effectively disrupts biofilms and reduces bacterial load without causing significant damage to surrounding tissues. It has demonstrated beneficial effects in the treatment of chronic periodontitis, peri-implantitis, and endodontic infections. An additional advantage of PDT is its reduced risk of promoting antimicrobial resistance compared with conventional antibiotics. Nevertheless, variability in photosensitizers, light sources, and treatment protocols requires further standardization for widespread clinical use.[19]

Probiotics and Prebiotics

Probiotics and prebiotics represent novel biological approaches for maintaining oral microbial balance. Probiotic microorganisms such as Lactobacillus and Bifidobacterium species can inhibit pathogenic bacteria through competitive adhesion, production of antimicrobial substances, and modulation of host immune responses. Prebiotics selectively stimulate the growth of beneficial oral microorganisms, promoting a healthier oral microbiome. These therapies may help reduce periodontal inflammation, halitosis, and dental caries while supporting long-term ecological balance within the oral cavity. Although promising, additional clinical studies are required to establish optimal strains, dosages, and treatment durations for routine dental practice.[10,12,29]

Nanotechnology-Based Approaches

Nanotechnology-based therapies have gained significant attention in recent years for their potential in oral biofilm management. Nanoparticles containing silver, chitosan, zinc oxide, titanium dioxide, and other bioactive materials exhibit strong antimicrobial properties against oral pathogens. Due to their extremely small size, nanoparticles can penetrate biofilm matrices more effectively than conventional antimicrobial agents. They may disrupt microbial cell walls, generate reactive oxygen species, and interfere with microbial metabolism. Nanotechnology also enables the development of targeted drug delivery systems with improved therapeutic efficacy and reduced toxicity. Despite encouraging results, concerns regarding long-term biocompatibility and safety require further investigation before routine clinical application.[20,30]

Laser Therapy

Laser-assisted periodontal therapy is increasingly used as an adjunctive treatment for oral biofilm-associated diseases.

Dental lasers provide effective decontamination of periodontal pockets by destroying pathogenic microorganisms and removing diseased tissues. Laser therapy also promotes haemostasis, reduces postoperative pain, and enhances tissue healing through bio stimulatory effects. Different laser systems, including diode lasers, Nd: YAG lasers, and Er: YAG lasers, have shown beneficial outcomes in periodontal treatment. Although laser therapy offers several clinical advantages, its effectiveness depends on appropriate case selection, operator skill, and correct treatment parameters. It is generally recommended as a complementary approach alongside conventional mechanical therapy.[16,19]

AYURVEDIC AND HERBAL APPROACHES

Ayurveda describes oral hygiene and disease prevention through practices such as *Dantadhavana* (tooth cleansing), *Gandusha* (oil holding), and *Kavala* (gargling), which help maintain oral cleanliness and balance of doshas. Classical Ayurvedic texts including *Charaka Samhita*, *Sushruta Samhita*, and *Ashtanga Hridaya* emphasize preventive oral healthcare and the use of medicinal herbs for management of oral diseases. Herbal formulations such as Triphala, Neem, and Haridra possess antimicrobial, anti-inflammatory, antioxidant, and wound-healing properties that may help control oral biofilms and gingival inflammation. Oil pulling therapy has also demonstrated beneficial effects in reducing plaque accumulation and gingivitis. Phyto therapeutic agents are increasingly explored as safer adjuncts to conventional therapies because of their reduced side effects and lower risk of antimicrobial resistance.[21,22,23,24,25,26,27,28]

Ayurvedic Perspective of Oral Biofilms

Ayurveda describes oral diseases under Mukharoga.[26,27,28] According to Ayurvedic principles, derangement of Doshas, particularly Kapha and Rakta, contributes to diseases affecting the oral cavity. Accumulation of food debris, poor oral hygiene, and imbalance of Doshas may create conditions favourable for microbial growth and inflammation.

Classical Ayurvedic texts emphasize preventive oral hygiene measures such as:

- Dantadhavana (cleaning teeth)
- Jihwanirlekhana (tongue scraping)
- Gandusha (oil holding)
- Kavala (gargling)
- Pratisarana (local application of medicines)
- Nasya (nasal administration)

These procedures help maintain oral hygiene, reduce microbial load, and improve oral immunity.

Ayurvedic Drugs and Formulations in Oral Diseases

Several Ayurvedic herbs possess antimicrobial, anti-inflammatory, antioxidant, analgesic, and wound-healing properties.

ACTION OF AYURVEDIC DRUGS ON BIOFILM (WOUND) AND THEIR ROLE IN WOUND HEALING

Ayurvedic drugs possess antimicrobial, anti-inflammatory, antioxidant, and wound-healing properties that help in disrupting biofilms, penetrating the extracellular polymeric substance (EPS) matrix, and promoting tissue repair. These herbal agents act through multiple mechanisms such as inhibition of microbial adhesion, destruction of microbial cell walls, suppression of quorum sensing, reduction of inflammation, and stimulation of tissue regeneration.

Triphala

Triphala, a combination of *Haritaki (Terminalia chebula), Bibhitaki (Terminalia bellirica),* and *Amalaki (Emblica officinalis),* contains tannins, gallic acid, and flavonoids that disrupt the EPS matrix of biofilms and inhibit bacterial adhesion. Its antioxidant activity reduces oxidative stress in wounds, while its antimicrobial properties suppress pathogenic microorganisms and promote granulation tissue formation.[21,25]

Neem (*Azadirachta indica*)

Neem contains bioactive compounds such as nimbidin, azadirachtin, and quercetin that exhibit strong antimicrobial and antibiofilm activity. Neem penetrates the biofilm matrix, inhibits microbial colonization, and interferes with quorum sensing mechanisms required for biofilm maturation. It also possesses anti-inflammatory and immunomodulatory effects that accelerate wound healing and reduce infection.[22,25]

Haridra (*Curcuma longa*)

Haridra (Turmeric) contains curcumin, which has potent antimicrobial, antioxidant, and anti-inflammatory properties. Curcumin penetrates the biofilm matrix and damages microbial cell membranes, thereby reducing biofilm viability. It also inhibits inflammatory mediators, enhances collagen synthesis, and promotes angiogenesis and epithelialization in wounds.[23,25]

Arjun (*Terminalia arjuna*)

Arjun contains tannins, triterpenoids, and flavonoids that possess antimicrobial and astringent properties. These compounds help disrupt microbial biofilms and reduce microbial load within wounds. Arjun also promotes wound contraction, collagen maturation, and tissue remodeling, thereby facilitating faster healing.[25]

Jatyadi Taila

Jatyadi Taila is a classical Ayurvedic medicated oil containing herbs such as *Jati, Neem, Haridra,* and *Yashtimadhu*. The lipid-based formulation enhances deep penetration of active phytochemicals into wound tissues and biofilms. It helps soften and disrupt the EPS matrix, reduces microbial contamination, decreases inflammation, and stimulates granulation tissue formation and epithelial regeneration. Its soothing and moisturizing properties further support wound repair.[26,27,28]

Irimedadi Taila

Irimedadi Taila contains herbal ingredients such as *Neem, Haridra, Manjistha,* and *Lavanga* processed in an oil medium. The oil base facilitates penetration into infected tissues and biofilm layers. It exhibits antimicrobial, anti-inflammatory, and antioxidant activities that help reduce microbial burden and prevent further biofilm formation.

Irimedadi Taila also improves local circulation, reduces pain and swelling, and promotes healing of oral wounds and periodontal tissues.[22,23,25]

OVERALL MECHANISM IN BIOFILM AND WOUND HEALING

Collectively, these Ayurvedic drugs act by:

- Disrupting the extracellular polymeric substance (EPS) matrix
- Inhibiting microbial adhesion and quorum sensing
- Increasing permeability of microbial cell walls
- Reducing inflammation and oxidative stress
- Enhancing collagen synthesis and angiogenesis
- Promoting granulation tissue formation and epithelialization

These combined effects help break down biofilms, control infection, and accelerate wound healing in chronic and infected wounds.[20,21,25]

Oil Pulling Therapy, Kavala, and Gandusha in Management of Oral Biofilm and Oral Wound Healing.

Ayurveda describes several oral cleansing and therapeutic procedures collectively known as *Mukha Swasthya Rakshana* (maintenance of oral health). Among them, *Oil Pulling Therapy, Kavala,* and *Gandusha* are important procedures used for prevention and management of oral diseases, oral biofilms, gingivitis, ulcers, and wound healing. These procedures utilize medicated oils, herbal decoctions, and medicated liquids that possess antimicrobial, anti-inflammatory, antioxidant, and wound-healing properties.[24,26,27,28]

1. Oil Pulling Therapy (*Taila Gandusha/Kavala*)

Oil pulling is an ancient Ayurvedic oral detoxification procedure in which medicated oil is retained or swished in the mouth for a specific duration. Sesame oil and coconut oil are commonly used bases due to their lipid-soluble penetration ability and antimicrobial activity.[24]

Common Oils Used

- Sesame oil (*Tila Taila*)
- Coconut oil
- Irimedadi Taila
- Jatyadi Taila
- Neem oil
- Triphala oil preparations

MECHANISM OF ACTION ON ORAL BIOFILM

Oil pulling helps reduce oral biofilm by several mechanisms

- The viscous oil layer adheres to plaque and microbial colonies, mechanically loosening biofilm from tooth and mucosal surfaces.
- Lipid-soluble phytochemicals penetrate the extracellular polymeric substance (EPS) matrix and destabilize microbial adhesion.
- Oils reduce bacterial coaggregation and inhibit plaque formation.
- Fatty acids and herbal constituents exhibit antimicrobial action against *Streptococcus mutans* and periodontal pathogens.
- Antioxidant and anti-inflammatory components reduce gingival inflammation and promote healing of oral ulcers and wounds.

Wound Healing Effects

Oil pulling lubricates oral tissues, reduces dryness, improves circulation, and promotes epithelial regeneration and tissue repair. It also reduces microbial load, thereby preventing secondary infection in oral wounds and ulcers.[21,22,23,24]

2. Kavala Procedure

Kavala refers to holding a smaller quantity of medicated liquid in the mouth and gargling or swishing it actively. Unlike Gandusha, the liquid can be moved within the oral cavity.[26,27]

Common Drugs and Decoctions Used in Kavala

- Triphala Kwatha (decoction)
- Yashtimadhu decoction
- Neem decoction
- Turmeric water
- Khadira decoction
- Irimedadi Taila
- Sesame oil

ACTION ON ORAL BIOFILM

Kavala acts by

- Physically dislodging loosely attached biofilms from teeth and mucosa.
- Allowing herbal phytochemicals to penetrate microbial biofilm channels.
- Inhibiting quorum sensing and bacterial communication required for biofilm maturation.
- Reducing EPS production and microbial adhesion.
- Lowering oral acidity and suppressing pathogenic bacteria.

Oral Wound Healing Benefits

The anti-inflammatory and antioxidant effects of herbs like Haridra, Triphala, and Yashtimadhu reduce tissue inflammation, oxidative stress, pain, and edema. Kavala also improves salivary secretion, enhances cleansing, and accelerates healing of gingivitis, stomatitis, and oral ulcers.[21,23,25]

3. Gandusha Procedure

Gandusha involves completely filling the oral cavity with medicated liquid and retaining it without movement for a fixed duration. This allows prolonged contact between the medicine and oral tissues.[26,27,28]

Types of Gandusha

- *Snigdha Gandusha* – oil-based
- *Shamana Gandusha* – cooling and anti-inflammatory
- *Shodhana Gandusha* – cleansing and detoxifying
- *Ropana Gandusha* – wound-healing formulations

Common Preparations Used

- Jatyadi Taila
- Irimedadi Taila
- Triphala decoction
- Neem decoction
- Honey-based preparations
- Haridra decoction
- Medicated ghee preparations

MECHANISM AGAINST ORAL BIOFILM

Gandusha provides prolonged exposure of herbal medicines to biofilms and wounds, which:

- Softens and disrupts the EPS matrix.
- Enhances penetration of active herbal compounds into deeper biofilm layers.
- Inhibits microbial metabolism and toxin production.
- Reduces bacterial and fungal colonization.
- Forms a protective coating over ulcerated mucosa and wounds.

ROLE IN ORAL WOUND HEALING

Gandusha promotes healing by:

- Reducing inflammation and pain
- Improving local blood circulation
- Stimulating fibroblast activity and collagen synthesis
- Enhancing granulation tissue formation
- Accelerating epithelialization of oral ulcers and wounds

These procedures are particularly useful in conditions such as gingivitis, periodontitis, stomatitis, mucositis, aphthous ulcers, post-extraction wounds, and oral infections.[22,23,24,25]

IMPORTANT AYURVEDIC DRUGS USED IN ORAL BIOFILM AND WOUND HEALING

Table 1.

Ayurvedic Drug	Major Action on Biofilm	Wound Healing Effect
Triphala	Disrupts EPS matrix, antimicrobial	Antioxidant, promotes granulation
Neem	Inhibits adhesion and quorum sensing	Anti-inflammatory, antimicrobial
Haridra (Turmeric)	Penetrates biofilm, damages microbial membrane	Enhances collagen synthesis
Yashtimadhu	Reduces inflammation and microbial growth	Soothing and epithelial healing
Arjun	Astringent, reduces microbial load	Tissue contraction and repair
Jatyadi Taila	Deep penetration into wound biofilm	Granulation and epithelialization
Irimedadi Taila	Antimicrobial and anti-plaque	Periodontal healing

Overall Effect on Oral Biofilm and Oral Wounds

Collectively, Oil Pulling, Kavala, and Gandusha help in:

- Mechanical removal of oral biofilms
- Penetration and disruption of the EPS matrix
- Suppression of pathogenic microorganisms
- Inhibition of quorum sensing and plaque maturation
- Reduction of inflammation and oxidative stress
- Promotion of collagen formation and epithelial regeneration
- Faster healing of oral wounds and ulcers

Thus, these Ayurvedic procedures serve as valuable adjunctive therapies in the management of oral biofilm-associated diseases and oral wound healing.[21,22,23,24,25,26,27,28]

ROLE OF AYURVEDIC DRUGS IN OVERCOMING LIMITED DRUG PENETRATION IN ORAL BIOFILMS

The extracellular polymeric substance (EPS) matrix of oral biofilms acts as a dense protective barrier that prevents adequate penetration of antimicrobial agents into deeper microbial layers. This matrix contains polysaccharides, proteins, lipids, extracellular DNA (eDNA), and water channels that trap or neutralize antimicrobial molecules before they reach pathogenic microorganisms. Microorganisms located in deeper layers often remain in dormant or slow-growing states, making them highly resistant to conventional antibiotics.[4,11,14,30]

Ayurvedic drugs and medicated formulations may help overcome these limitations through multiple phytochemical and physicochemical mechanisms that enhance biofilm penetration, disrupt EPS integrity, inhibit microbial communication, and promote wound healing.

HOW AYURVEDIC DRUGS ACT ON BIOFILM AND IMPROVE DRUG PENETRATION

1. Disruption of EPS Matrix

Many Ayurvedic herbs contain tannins, phenolics, flavonoids, alkaloids, terpenoids, and essential oils that chemically destabilize the EPS matrix.

Triphala

Triphala contains:

- Gallic acid

- Ellagic acid
- Chebulinic acid
- Tannins

These phytochemicals can:

- Break hydrogen bonding within polysaccharides
- Chelate metal ions stabilizing the matrix
- Reduce EPS viscosity
- Destabilize microbial adhesion

As the EPS matrix becomes loosened, deeper penetration of antimicrobial molecules becomes possible.[21,25]

Neem (*Azadirachta indica*)

Neem contains:

- Nimbidin
- Azadirachtin
- Gedunin
- Quercetin

These compounds

- Inhibit microbial adhesion proteins
- Interfere with biofilm maturation
- Suppress EPS synthesis
- Increase permeability of microbial membranes

Neem phytochemicals can penetrate lipid-rich microbial layers because many are lipophilic in nature.[22,25]

2. Penetration through Lipophilic Nature of Oils

Ayurvedic medicated oils such as:

- Jatyadi Taila
- Irimedadi Taila
- Sesame oil-based formulations

Contain lipid-soluble phytochemicals that diffuse through biofilm lipid components and microbial membranes.

Mechanism

The oil medium:

- Softens the biofilm matrix
- Increases permeability of microbial membranes
- Enhances diffusion of herbal active compounds
- Facilitates deeper penetration into wound tissues

Sesame oil itself possesses

- Oleic acid
- Linoleic acid
- Sesamol

Which show antioxidant and membrane-penetrating properties. Oil molecules may also disrupt hydrophobic interactions within the biofilm matrix.[24,25]

3. Quorum Sensing Inhibition

Biofilm microorganisms communicate through quorum sensing molecules that regulate:

- EPS production
- Virulence
- Biofilm maturation
- Antibiotic resistance

Ayurvedic phytochemicals can inhibit this communication.

Haridra (*Curcuma longa*)

Curcumin

- Suppresses quorum sensing genes
- Reduces bacterial signalling molecules
- Prevents biofilm maturation
- Inhibits bacterial virulence factors

This weakens biofilm architecture and makes microorganisms more susceptible to antimicrobial attack.[23,25]

4. Oxidative Damage to Biofilm Cells

Several Ayurvedic herbs generate oxidative stress within microbial cells.

Phytochemical Action

Polyphenols and flavonoids:

- Damage bacterial membranes
- Denature microbial proteins
- Alter enzyme activity
- Produce reactive oxygen species (ROS)

This weakens microorganisms inside deeper biofilm layers.

Examples

- Curcumin from Haridra
- Tannins from Arjun and Triphala
- Flavonoids from Neem

These compounds impair microbial survival even in dormant bacterial populations.[21,22,23]

5. Enzymatic and Protein-Denaturing Effects

Some herbal constituents may degrade proteins and extracellular components within biofilms.

Arjun (*Terminalia arjuna*)

Arjun contains

- Triterpenoids
- Tannins
- Saponins

These compounds

- Denature extracellular proteins
- Destabilize microbial enzymes
- Reduce microbial attachment strength

This helps weaken the biofilm scaffold and enhances penetration of therapeutic agents.[25]

6. Anti-inflammatory and Wound-Healing Actions

After biofilm disruption, Ayurvedic drugs promote tissue repair through:

- Fibroblast stimulation
- Collagen synthesis
- Angiogenesis
- Epithelialization

Jatyadi Taila

Contains herbs such as:

- Neem
- Haridra
- Jati
- Yashtimadhu

These reduce inflammation and accelerate granulation tissue formation.

Yashtimadhu (*Glycyrrhiza glabra*)

Contains glycyrrhizin which:

- Reduces inflammatory cytokines
- Promotes epithelial regeneration
- Accelerates wound closure

Thus, Ayurvedic drugs not only disrupt biofilms but also create a favorable environment for oral wound healing.[25,26,27,28]

PHYTOCHEMICAL REACTIONS INVOLVED IN BIOFILM DISRUPTION

Table 2.

Phytochemical	Source	Action on Biofilm
Curcumin	Haridra	Quorum sensing inhibition, ROS generation
Gallic acid	Triphala	EPS destabilization, antioxidant
Tannins	Triphala, Arjun	Protein precipitation, adhesion inhibition
Nimbidin	Neem	Antimicrobial membrane disruption
Flavonoids	Neem, Triphala	Oxidative stress induction
Sesamol	Sesame oil	Lipid penetration and antioxidant action
Saponins	Arjun	Increased membrane permeability

ASSESSMENT OF EFFECTIV OF AYURVEDIC DRUGS AGAINST BIOFILMS

Scientific validation can be performed through microbiological, molecular, and clinical studies.

1. In Vitro Biofilm Assays

Crystal Violet Assay

Measures reduction in biofilm biomass after herbal treatment.

Minimum Biofilm Eradication Concentration (MBEC)

Determines concentration required to eradicate biofilm microorganisms.

Agar Diffusion and MIC Tests

Assess antimicrobial activity of herbal extracts.

2. Microscopic Evaluation

Confocal Laser Scanning Microscopy (CLSM)

Demonstrates:

- Biofilm thickness reduction
- EPS disruption
- Dead bacterial cells after treatment

Scanning Electron Microscopy (SEM)

Shows:

- Structural damage to biofilm
- Reduced microbial aggregation
- Surface disruption

Transmission Electron Microscopy (TEM)

Reveals:

- Membrane damage
- Intracellular degeneration

3. Molecular Studies

PCR and Gene Expression Analysis

Can evaluate suppression of:

- Quorum sensing genes
- EPS synthesis genes
- Virulence genes

After treatment with Ayurvedic phytochemicals.

4. Clinical Studies

Clinical parameters can demonstrate therapeutic success:

- Reduction in plaque index
- Reduction in gingival index
- Decreased periodontal pocket depth
- Faster oral ulcer healing
- Reduced microbial counts

Studies on

- Triphala mouthwash
- Neem preparations
- Oil pulling therapy
- Irimedadi Taila

have shown improvement in gingivitis, plaque control, and oral wound healing.[21,22,23,24]

INTEGRATIVE APPROACH: AYURVEDA AND MODERN MEDICINE

An integrative approach combining modern dental care with Ayurvedic therapies may improve outcomes in oral biofilm-associated diseases. Mechanical plaque removal combined with herbal mouthwashes, oil pulling, and antioxidant therapies may reduce microbial load and inflammation.

Ayurvedic formulations may help minimize antibiotic use and reduce adverse effects associated with long-term antimicrobial therapy. Herbal agents with biofilm-disrupting activity may serve as adjuncts to conventional periodontal treatment.

Future research should focus on standardization of herbal formulations, clinical trials, pharmacological evaluation, and molecular mechanisms of Ayurvedic drugs against oral biofilms.[20,25]

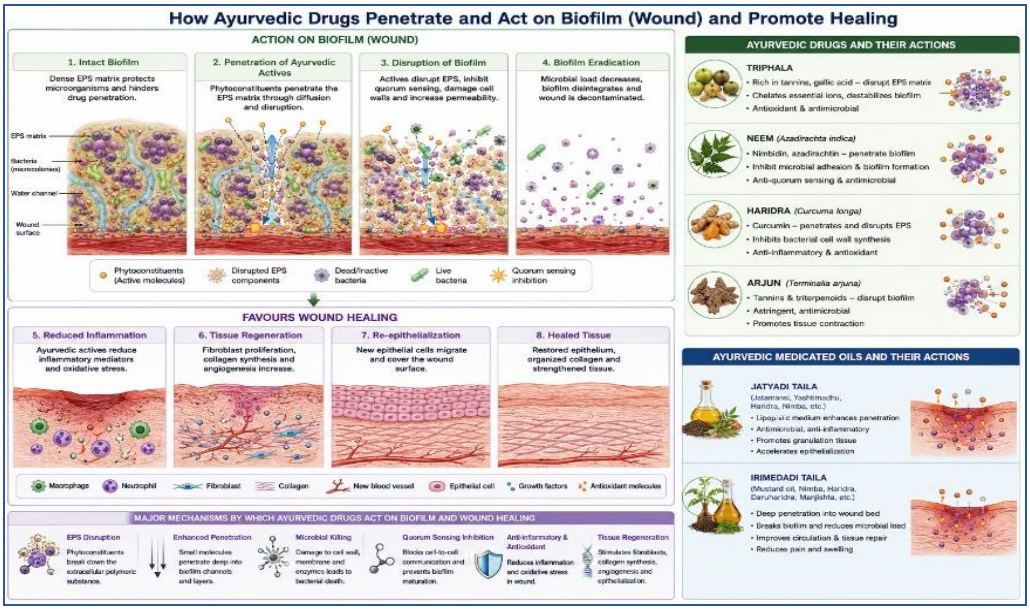


Photo 2.

CONCLUSION

Oral biofilms play a significant role in the pathogenesis of several chronic oral diseases including dental caries, gingivitis, periodontitis, peri-implantitis, and oral candidiasis. Advances in molecular diagnostics, imaging techniques, and salivary biomarkers have improved understanding and early detection of oral biofilms. However, antimicrobial resistance, biofilm persistence, and recurrence continue to pose major therapeutic challenges.

Ayurveda provides a comprehensive approach for oral health maintenance through preventive practices, herbal formulations, and local therapeutic procedures. Integration of Ayurvedic principles with modern dental sciences may offer safe, effective, and holistic strategies for the management of biofilm-associated oral diseases. Further scientific validation and clinical research are essential to establish evidence-based integrative therapies.

Ayurvedic drugs act against oral biofilms through a multifactorial mechanism involving EPS disruption, quorum sensing inhibition, membrane destabilization, oxidative microbial damage, and enhanced penetration through lipid-based formulations. Unlike conventional antibiotics that often fail to penetrate deeper biofilm layers, Ayurvedic phytochemicals and medicated oils may weaken biofilm architecture and improve therapeutic diffusion. Simultaneously, these drugs promote wound healing through anti-inflammatory, antioxidant, collagen-stimulating, and tissue regenerative effects. Their effectiveness can be scientifically validated through microbiological assays, microscopy, molecular studies, and clinical trials.

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