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Oral Health - Systemic and Public Health Approaches

Edited by Alicja Zawiślak

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Aims and Scope of the Series

This book series will offer a comprehensive overview of recent research trends as well as clinical applications within different specialties of dentistry. Topics will include overviews of the health of the oral cavity, from prevention and care to different treatments for the rehabilitation of problems that may affect the organs and/or tissues present. The different areas of dentistry will be explored, with the aim of disseminating knowledge and providing readers with new tools for the comprehensive treatment of their patients with greater safety and with current techniques. Ongoing issues, recent advances, and future diagnostic approaches and therapeutic strategies will also be discussed. This series of books will focus on various aspects of the properties and results obtained by the various treatments available, whether preventive or curative.

Meet the Series Editor

Dr. Sergio Alexandre Gehrke is a doctorate holder in two fields. The first is a Ph.D. in Cellular and Molecular Biology from the Pontificia Catholic University, Porto Alegre, Brazil, in 2010 and the other is an International Ph.D. in Bioengineering from the Universidad Miguel Hernandez, Elche/Alicante, Spain, obtained in 2020. In 2018, he completed a postdoctoral fellowship in Materials Engineering in the NUCLEMAT of the Pontificia Catholic University, Porto Alegre, Brazil. He is currently the Director of the Postgraduate Program in Implantology of the Bioface/UCAM/PgO (Montevideo, Uruguay), Director of the Cathedra of Biotechnology of the Catholic University of Murcia (Murcia, Spain), an Extraordinary Full Professor of the Catholic University of Murcia (Murcia, Spain) as well as the Director of the private center of research Biotecnos – Technology and Science (Montevideo, Uruguay). Applied biomaterials, cellular and molecular biology, and dental implants are among his research interests. He has published several original papers in renowned journals. In addition, he is also a Collaborating Professor in several Postgraduate programs at different universities all over the world.

Meet the Volume Editor

Dr. Alicja Zawiślak is an orthodontist specializing in orofacial clefts and craniofacial malformations, as well as a molecular biologist. She earned degrees from Pomeranian Medical University (Poland), the University of Greifswald (Germany), and Jagiellonian University (Poland). She holds an Orthodontics Specialist title and a Ph.D., during which she led research on genetic predisposition to clefts. Dr. Zawiślak completed a postdoctoral fellowship at the University of Navarra (Spain) and internships at the University of Murcia (Spain), the University of Milan (Italy), the University of Rijeka (Croatia), the International Catalan University (Spain), and the University of Alexandria (Egypt). She is the Acting Head of Maxillofacial Orthopaedics and Orthodontics at the Institute of Mother and Child in Warsaw and an Associate Professor at Pomeranian Medical University in Szczecin.

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Preface

Oral health is fundamental to overall well-being and plays a crucial role far beyond the boundaries of the mouth. Increasing evidence suggests that the condition of the oral cavity has a significant impact on systemic health, influencing the development and progression of various chronic diseases, including cardiovascular disorders, diabetes, and respiratory conditions. Understanding these complex bidirectional relationships is essential for advancing both clinical practice and public health initiatives.

This book aims to provide an integrated perspective on oral health, systemic health, and public dentistry, highlighting their interconnected nature and mutual influence. By combining foundational knowledge with cutting-edge research, clinical insights, and community-based approaches, it addresses prevention, diagnosis, and management strategies that transcend traditional disciplinary divides. The inclusion of developmental dentistry, oral pathology, and modern preventive practices reflects the multi-faceted approach required to enhance health outcomes at both individual and population levels.

Public dentistry, as a field dedicated to promoting oral health equity and accessibility, plays a vital role in bridging clinical care with broader public health goals. Its integration with systemic health perspectives fosters holistic care models that benefit both communities and healthcare systems.

I extend my deepest gratitude to the editors and all contributors whose expertise, dedication, and collaborative efforts have made this comprehensive work possible. Their commitment to advancing knowledge and practice in this interdisciplinary field is invaluable, and I hope that this book serves as a valuable resource for clinicians, researchers, public health professionals, educators, and all readers interested in understanding the vital connections between oral, systemic, and public health.

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Section 1

Oral Health and Systemic Interconnections

Chapter 1

A Two-Way Street: Oral Health and Systemic Diseases

Ramona Dumitrescu, Octavia Balean, Vanessa Bolchis and Daniela Jumanca

Abstract

The bidirectional relationship between oral health and systemic wellness highlights how maintaining a healthy oral environment is essential for overall well-being, significantly influencing both physical health and quality of life. Oral diseases such as gingivitis, periodontitis, and dental caries can reflect and influence systemic conditions, with chronic inflammation in the mouth playing a significant role in triggering and perpetuating non-communicable diseases (NCDs) such as cardiovascular disorders and diabetes. It is also believed that over 100 systemic diseases and approximately 500 medications are linked to oral manifestations, particularly among older adults. The intensity of this relationship can be amplified by shared risk factors such as tobacco use and stress. The oral microbiome also plays a pivotal role in shaping systemic health, with imbalances in its composition capable of triggering a wide range of broader health issues. Inflammation is the common denominator between oral and systemic health, acting as a bridge between these conditions. Chronic oral inflammation can enhance systemic inflammation, worsening overall health outcomes. Insufficient understanding and awareness of the connections between oral health and significant systemic conditions have led to a decline in quality of life. This interconnection impacts the quality of life, as oral pain, chewing difficulties, and dental esthetics can impair physical, psychological, and social well-being. A preventive approach and interdisciplinary care are essential in managing both oral and systemic health. Collaboration between dentists and other healthcare professionals is key to improving patient outcomes and quality of life.

Keywords: systemic diseases, inflammation, oral microbiome, interdisciplinary care, risk factors

1. Introduction

Oral health is an integral component of overall health and well-being, yet it remains one of the most neglected areas in public health discussions despite its profound implications for systemic diseases. According to the Global Burden of Disease Study (2019), oral diseases affect nearly 3.5 billion people worldwide, with untreated dental caries being the most prevalent condition globally. Periodontitis, oral cancers, and edentulism significantly impact quality of life and contribute to socioeconomic inequalities [1]. The World Health Organization (WHO) 2030 Agenda for Sustainable Development emphasizes the need for universal health coverage and highlights the interconnection between oral health and the broader determinants of non-communicable diseases (NCDs) such as cardiovascular diseases, diabetes, and cancers [2]. This chapter explores the dynamic relationship between oral health and systemic diseases, delving into the shared risk factors, microbial mechanisms, and socioeconomic determinants that link these conditions. By integrating insights from recent research and public health initiatives, it aims to underscore the importance of interdisciplinary collaboration, preventive strategies, and policy reforms to address global oral health disparities. This approach aligns with the WHO's (World Health Organization) vision for 2030, emphasizing the need for equitable, accessible, and integrated healthcare systems to reduce the global burden of disease and improve population health outcomes.

2. Oral health and systemic health: A dual pathway

The oral cavity serves as a crucial intersection between medicine and dentistry and provides insights into a patient's overall health. Numerous diseases and medications impact the oral cavity, and conditions in the mouth can have more systemic effects than many clinicians realize. The relationships between periodontal and systemic conditions such as atherosclerotic vascular disease, lung disease, diabetes, pregnancy complications, osteoporosis, and kidney disease remain under debate, with uncertainty about whether these associations are causal or merely in correlation. A common characteristic of periodontal disease and these medical conditions is their chronic nature, often requiring years to develop into clinically significant issues. The challenge lies in primary prevention—addressing health concerns before symptoms, such as myocardial infarction, stroke, diabetic complications, or advanced periodontal disease, manifestly. These complications lead to considerable morbidity, mortality, and healthcare costs. However, many patients lack access to primary medical or dental care, delaying engagement with the healthcare system until a critical event occurs. Despite the unclear causality, the population-level consequences of these chronic conditions are well understood. Enhanced collaboration and communication among dentists, family physicians, and primary care providers are essential to optimize patient outcomes. Without proper oral care, bacterial growth can lead to conditions such as tooth decay and gum disease. Additionally, medications such as decongestants, antihistamines, pain relievers, diuretics, and antidepressants can reduce saliva production that is vital for sweeping away food, neutralizing bacterial acids, and protecting against oral diseases.

The relationship between periodontitis and systemic diseases has become a central focus of clinical periodontal research, with significant growth in research activity since the late 1980s. Today, nearly one-third of all periodontal studies explore this connection, encompassing a total of 57 systemic conditions being investigated in relation to periodontal diseases. This expansive area of study highlights the increasing recognition of the interplay between oral and systemic health. This relationship is often described as "two-way" or "bi-directional." However, many observational epidemiological studies lack the design to firmly establish the directionality of these associations. By default, any identified connections are considered bi-directional until further data provide definitive clarification. While numerous associations have been reported, their significance and potential role in causation remain areas of ongoing investigation [3].

The connection between oral health and overall general health has gained significant attention over the past two decades. Research has explored the links between periodontal status and various diseases or conditions, including cardiovascular disease, ischemic stroke, diabetes, pulmonary disease, low birth weight, prematurity, dementia, and certain cancers. Microbial infections, immune cross-reactivity, and inflammatory mediators are thought to be key factors increasing the risk of these diseases. Additionally, systemic conditions such as diabetes and cyclic neutropenia have been shown to substantially elevate the likelihood of developing periodontitis. A compromised immune system is a critical risk factor not only for gingivitis and periodontitis but also for oral infections like candidosis. This mutual relationship underscores the fact that good overall health and quality of life are unattainable without maintaining a healthy, disease-free oral environment. Timely and accurate diagnosis, along with early treatment, is crucial for mitigating the impact of periodontitis. Identifying severe cases is particularly important, as they pose greater therapeutic challenges and are associated with poorer tooth prognosis, increased tooth loss risk, higher treatment costs, and a greater potential to affect systemic health and overall well-being. Periodontitis is a significant public health issue due to its widespread prevalence and adverse effects on oral health, including tooth loss, esthetic concerns, and impaired chewing ability. It also has systemic implications, contributing to malnutrition and diminished quality of life, with substantial psychosocial and economic consequences [4]. Periodontal biofilm serves as a reservoir for bacteria that can lead to lower airway infections, particularly in older or debilitated patients, by inoculating the respiratory tract through aspiration. The severity of respiratory infections, such as bronchitis and pneumonia, is linked to the pathogenicity of bacteria in the biofilm, with periodontal and cariogenic pathogens increasing the risk of aspiration pneumonia. High-risk groups include medically compromised individuals, especially those in nursing homes or hospitals, who may struggle with adequate oral hygiene. Research from 328 articles over 11 years highlights the critical role of oral hygiene in reducing respiratory infections in elderly populations. Proper oral care, including frequent tooth brushing and the use of 0.12% chlorhexidine mouthrinse or gel, has been shown to significantly decrease the occurrence of nosocomial pneumonia and respiratory infections. Chlorine dioxide oral rinses, available over the counter, also reduce biofilm in the mouth and on removable prosthetics, lowering the risk of aspiration pneumonia. Implementing daily chlorhexidine or chlorine dioxide rinses in elderly patients, particularly those with limited manual dexterity, is recommended as an effective preventive measure against aspiration pneumonia. This approach could prevent significant morbidity and mortality, especially in institutionalized elderly individuals [5]. Respiratory diseases such as bronchopulmonary dysplasia and asthma significantly influence oral health. Common manifestations include enamel defects, an increased risk of caries, and candidiasis due to medication-induced salivary flow reduction. Obstructive sleep apnea is associated with mouth breathing, gingivitis, and open-bite malocclusions, often linked to airway obstructions. Cystic fibrosis patients experience enamel hypoplasia, gingival inflammation, and halitosis, largely exacerbated by the prolonged use of medications such as antibiotics and steroids [6].

The COVID-19 pandemic has reshaped our understanding of chronic and inflammatory conditions, including periodontal disease (PD). Both COVID-19 and chronic periodontitis (CP) share similar inflammatory mechanisms, particularly the cytokine storm phenomenon, involving elevated levels of cytokines such as IL-1β, IL-6, IL-10, IL-17, and metalloproteinases. The age group most affected by COVID-19, older individuals, is also commonly afflicted by CP, highlighting a potential link between these conditions. Periodontal pathogens can worsen COVID-19 outcomes by contributing to respiratory infections, particularly through aspiration or intubation. Additionally, CP may exacerbate age-related senescence, facilitating SARS-CoV-2 attachment and replication. Shared risk factors such as hypertension further compound the severity of COVID-19 in individuals with PD [7].

Cardiovascular diseases and their treatments pose unique challenges to oral health. Cyanotic congenital heart diseases can lead to violaceous mucosa, enamel hypoplasia, and increased caries risk, coupled with the potential for infectious endocarditis. Hypertension-related gingival overgrowth and rare occurrences of facial paralysis are often side effects of pharmacological interventions. Common cardiovascular medications, such as those managing blood pressure or cholesterol, frequently cause dry mouth, gingival overgrowth, and taste disturbances, elevating the risk of dental caries and oral infections [6]. Periodontal infections are also strongly linked to cardiovascular disease. Historical hypotheses associating chronic infection with vascular disease have gained empirical support in recent years. Periodontitis is correlated with an increased risk of myocardial infarction and stroke, particularly in younger individuals, smokers, and those with lower socioeconomic status. Biological mechanisms linking periodontal disease to CVD include direct pathways, where oral bacteria and endotoxins enter the bloodstream, potentially contributing to hypercoagulability and atherosclerosis, and indirect pathways, involving systemic inflammation. Elevated inflammatory markers such as C-reactive protein in individuals with periodontal disease further underscore this connection. While treating periodontal infections reduces inflammatory markers, no conclusive evidence links periodontal treatment to reduced clinical CVD events. Nonetheless, these findings highlight the critical interplay between oral health and systemic conditions, emphasizing the importance of early detection, comprehensive care, and integrated management strategies [8].

The global rise in obesity has led to an epidemic of metabolic syndrome and type 2 diabetes, with diabetes accounting for 2.6% of global disability-adjusted life years (DALYs) in 2019 [1]. The link between periodontal disease and metabolic syndrome likely stems from shared inflammatory pathways and advanced glycation end products. These conditions are influenced by various factors, including obesity, insulin resistance, genetic predispositions, and oral infections, which can impair endothelial function and disrupt glucose metabolism. Diabetes and periodontal disease form a bidirectional relationship: Diabetes increases susceptibility to oral infections, while these infections can worsen glycemic control. Research highlights that managing periodontal disease can enhance glycemic control in type 2 diabetes patients, and improved glycemic control can, in turn, benefit periodontal health. This interdependence underscores the importance of integrated care. Effective communication and collaboration between medical specialists managing diabetes and dental professionals are crucial to improving overall health outcomes and quality of life for patients [9].

Periodontal disease is strongly associated with systemic conditions such as osteoporosis, with studies suggesting a bidirectional relationship between the two [9]. Signaling pathways, such as the IL-17/Th17 pathway, regulate osteoclast activity. Although the exact mechanisms by which PD affects systemic bone density remain unclear, research highlights the role of inflammation in this connection. Anti-inflammatory therapies, including angiotensin II receptor I inhibitors, have demonstrated potential in preventing both periodontal inflammation and bone loss [7].

Rheumatic diseases encompass a wide range of conditions affecting collagen metabolism, often involving multiple organ systems. Among them, rheumatoid arthritis (RA), a systemic autoimmune disorder, accounted for 3.26 million global disability-adjusted life years (DALYs) in 2019 [1]. RA shares several risk factors and pathogenic pathways with periodontitis, including genetic predispositions and external influences such as smoking, obesity, and socioeconomic factors. Periodontal pathogens, particularly *Porphyromonas gingivalis*, have been implicated in exacerbating RA by promoting protein citrullination, a process linked to the disease's pathogenesis. Evidence suggests that periodontal inflammation plays a significant role in RA. Studies show correlations between periodontal inflammation and RA severity, with baseline periodontal status influencing disease activity, swollen joint counts, and patient assessments. Interventional research has demonstrated that periodontal therapy can improve RA symptoms in patients unresponsive to standard synthetic and biological disease-modifying antirheumatic drugs (DMARDs), highlighting the importance of addressing oral health in RA management [10]. The impact of antirheumatic treatments on oral health remains an open question. Research indicates no direct association between RA drug treatments and periodontal parameters, but RA patients often exhibit poorer oral health compared to controls, even in early disease stages. Dental disease indices have been positively associated with RA activity, emphasizing the need for integrated care [9].

Alzheimer's disease, the leading cause of dementia, is a neurodegenerative condition influenced primarily by age and genetics. It involves the abnormal metabolism of amyloid precursor protein, leading to the deposition of ß-amyloid plaques in the brain. Central nervous system inflammation is thought to play a role in triggering this process. Alzheimer's disease accounts for approximately 1% of global disability-adjusted life years (DALYs), affecting millions worldwide [1]. Recent studies have explored the potential association between periodontitis and Alzheimer's disease. Periodontitis, a chronic inflammatory condition, may exacerbate cerebral inflammation by upregulating cytokines and inflammatory mediators. Additionally, periodontal pathogens, particularly *P. gingivalis*, and its metabolites, such as gingipains, have been detected in the brain tissues of Alzheimer's patients. These findings suggest a possible role of periodontal bacteria in amyloid-ß accumulation, a hallmark of Alzheimer's pathology [11, 12]. Despite these intriguing associations, the evidence remains inconclusive. A systematic review by Dioguardi et al. [13] analyzed the existing literature and found only 15 studies meeting stringent criteria. The authors concluded that while periodontitis might influence the inflammatory pathways linked to Alzheimer's, more research is needed. Future studies should focus on understanding the impact of reducing periodontal inflammation and clarifying the role of periodontal bacteria in Alzheimer's pathogenesis. This highlights the potential importance of oral health in mitigating risks for neurodegenerative diseases.

Kidney and liver diseases are significant global health concerns, with chronic kidney disease (CKD) contributing to 41.5 million disability-adjusted life years (DALYs) and chronic liver diseases accounting for 46.2 million DALYs globally in 2019. Dental diseases are highly prevalent among patients with these conditions, often exacerbating their severity. For example, periodontal disease is more common in patients with severe CKD compared to those with less severe disease, and treatment of periodontitis has been shown to improve glomerular filtration rates. Diabetic nephropathy, the leading cause of CKD in many countries, increases susceptibility to dental infections, which can further impact overall health outcomes. Similarly, liver diseases, including cirrhosis and liver cancer, pose significant global health challenges. Oral health is crucial for patients with liver diseases, especially those awaiting liver transplantation (LT). Pre-transplant dental treatment is essential to reduce the risk of post-transplant systemic infections, as poor oral health correlates with complications. Chronic liver diseases, including cirrhosis, are linked to common oral issues such as caries and periodontitis, as well as hyposalivation, which increases the risk of oral infections and negatively impacts quality of life. Periodontitis has been identified as an independent risk factor for severe chronic liver disease, with poor oral health further worsening the progression of liver conditions. LT recipients often require extensive dental and periodontal care due to poor oral hygiene and a heightened risk of infections, emphasizing the critical role of oral health management in patients with kidney and liver diseases [9].

Infectious diseases often exhibit oral manifestations, reflecting their systemic impact. Primary herpetic gingivostomatitis, caused by HSV-1, manifests with painful swelling, erythema, vesicles, and ulcers on the gingiva and oral mucosa, often accompanied by fever and lymphadenopathy. Similarly, varicella (chickenpox) produces mild oral vesicles and ulcers that precede widespread skin lesions. Infections like infectious mononucleosis, linked to the Epstein-Barr virus, present with pharyngitis, palatal petechiae, and necrotizing gingivitis. Hand-foot-mouth disease and herpangina, caused by enteroviruses, result in vesicles and ulcers in the oropharynx, often accompanied by fever and systemic symptoms. In immunocompromised individuals or those with HIV, recurrent herpes simplex infections, candidiasis, and linear gingival erythema are key indicators of immune suppression, highlighting the intersection between systemic immunity and oral health [6].

Chronic periodontitis (CP) is associated with systemic inflammation and pathogen migration, which have significant implications for obstetric complications. Hormonal changes during pregnancy increase vascular permeability in gingival tissues, facilitating the entry of pathogens and their byproducts into the bloodstream and potentially reaching the placenta. This can trigger immune and inflammatory responses, leading to elevated pro-inflammatory cytokine levels that may harm fetal tissues. Such fetal inflammation increases the risk of complications such as premature rupture of membranes, uterine contractions, miscarriage, or preterm delivery [7]. Evidence suggests a link between periodontitis and preterm delivery or low birth weight. Biofilm-related inflammatory molecules can enter the bloodstream, cross the placenta, and affect fetal membranes. Periodontal pathogens, identified in fetal membranes, produce lipopolysaccharides that trigger prostaglandin production. These prostaglandins, released into the circulatory system, stimulate oxytocin production, potentially initiating preterm labor and resulting in lower birth weight infants. The severity of periodontal inflammation often increases during pregnancy, further elevating the risk [5].

Additional connections between systemic diseases and the oral cavity often arise from the direct extension of the gastrointestinal (GI) tract into the mouth or the introduction of pathogens and allergens through the aerodigestive tract. For instance, Crohn's disease and oral ulcers, as well as tooth erosion linked to gastroesophageal reflux disease (GERD), are clear examples of oral manifestations stemming directly from digestive tract disorders. Gastroesophageal reflux disease (GERD) leads to dental erosion, hypersalivation, and palatal erythema, driven by chronic acid exposure. Inflammatory bowel diseases, such as ulcerative colitis and Crohn's disease, contribute to oral ulcers, cobblestone mucosal swelling, and gingival enlargement. Celiac disease, a gluten-sensitive enteropathy, causes enamel hypoplasia, delayed tooth eruption, and aphthous ulcers, primarily due to nutritional deficiencies. Eating disorders, including anorexia and bulimia, manifest as dental erosion, hypersensitivity, and mucosal pallor due to frequent acid exposure, nutritional deficiencies, and the effects of medications used to manage psychiatric comorbidities [6]. Many childhoods infectious diseases, such as primary herpetic gingivostomatitis, result from the spread of pathogens through oral secretions. However, most oral health issues associated with systemic conditions are indirectly influenced by hematologic, immunologic, endocrine, or neoplastic diseases and the therapeutic interventions used to manage these conditions [14].

3. Major oral conditions and their systemic impact

Oral health is intricately connected to overall systemic health, with several oral conditions influencing and reflecting broader health issues. Among these conditions, dental caries, periodontal disease, oral cancer, and oral manifestations in immunocompromised individuals are particularly significant, affecting millions globally. Understanding their causes, consequences, and systemic interactions is essential for devising effective prevention and management strategies [15]. The oral cavity offers significant value in clinical evaluation due to its ease of visualization, direct accessibility for palpation, and the less invasive nature of tissue sampling, imaging, and culturing. In many systemic diseases, oral manifestations are often the initial signs of the condition. Given the high prevalence of diseases affecting the mouth, comprehensive outlines have been created to emphasize the oral signs associated with major childhood diseases. The most common oral manifestations of systemic diseases vary depending on the affected primary organ system and the medications used in the treatment. Soft tissue findings frequently include oral ulcers, gingival bleeding, gingival enlargement, mucosal purpura, candidiasis, recurrent herpes simplex virus (HSV) infections, salivary hypofunction, glossitis, and lymphadenopathy. Common findings related to hard tissues often include periodontitis, enamel hypoplasia, dental caries, tooth discoloration, premature or delayed tooth eruption, reduced jawbone density, and temporomandibular joint disorders [16].

Dental caries is one of the most prevalent oral conditions worldwide, often termed a “silent epidemic.” It primarily results from the interaction of dietary-free sugars with microbial biofilms on teeth, leading to enamel demineralization. Caries disproportionately affects children, with severe consequences such as odontogenic infections and, in rare cases, mortality. Despite its prevalence, complacency and a lack of widespread preventive strategies persist, contributing to the global burden. Effective caries management requires balancing demineralization and remineralization processes. Prevention strategies, including fluoride toothpaste, water fluoridation, and dietary sugar reduction as recommended by the WHO, have proven effective. Advances in caries detection, such as the International Caries Classification and Management System (ICCMS™), emphasize early prevention and minimally invasive interventions. However, significant challenges remain, including addressing global inequalities in caries prevention and shifting from restorative to preventive approaches in healthcare systems [15]. Dental caries, a non-communicable, multifactorial disease, if untreated can lead to pain, abscesses, and tooth loss. A diet high in fermentable sugars is the primary cause of caries, while socioeconomic factors such as income, education, and access to dental care significantly influence its prevalence and severity. Globally, caries and obesity are interconnected public health issues in children and adolescents, with higher Gross National Income (GNI) per capita associated with increased Body Mass Index and caries prevalence. Additionally, income inequality and unemployment rates have been linked to higher caries severity, reflecting the impact of distal socioeconomic factors on the disease process by modulating causal factors such as diet, biofilm, and host susceptibility [17].

Periodontal diseases, including gingivitis and periodontitis, are chronic immuno-inflammatory disorders affecting the tooth-supporting structures. Gingivitis is reversible and characterized by inflammation of the gingival mucosa, whereas periodontitis involves alveolar bone destruction and can lead to tooth loss if untreated. Severe periodontitis is a leading cause of tooth loss globally and significantly impacts quality of life.

The pathogenesis of periodontitis is multifactorial, driven by dysbiosis in subgingival biofilms and a hyperactive host immune response. Contributing factors include genetic predisposition, systemic diseases such as diabetes mellitus, smoking, and socioeconomic determinants. Advanced diagnostic tools, including assays for inflammatory mediators, aid in identifying disease progression and risk. Prevention and management focus on controlling plaque biofilms, addressing modifiable risk factors, and emphasizing professional periodontal care. Increasing public awareness and improving oral health literacy are vital to reducing the global burden of periodontal diseases [15]. Periodontitis shares inflammatory mechanisms and genetic or acquired risk factors with several comorbid conditions, yet an independent association between periodontitis and these conditions persists even after adjusting for confounding factors. One contributing factor to this link is the ability of periodontitis to cause low-grade systemic inflammation, potentially influencing the development of comorbidities. Compared to healthy individuals, those with severe periodontitis exhibit elevated levels of pro-inflammatory mediators such as IL-1, IL-6, C-reactive protein (CRP), and fibrinogen, as well as increased blood neutrophil counts. A large-scale prospective study involving 11,869 participants demonstrated that poor oral hygiene is associated with elevated systemic inflammation and an increased risk of cardiovascular disease (CVD). Conversely, successful periodontal treatment reduces systemic inflammatory markers. The systemic inflammation associated with periodontitis likely arises from the dissemination of periodontal bacteria or inflammatory mediators into the bloodstream. The ulcerated epithelium of periodontal pockets, covering an area of 8–20 cm^2, provides a pathway for bacteria and their products (e.g., lipopolysaccharides or proteases) to enter the circulatory system, leading to bacteremia. Periodontal bacteria can also induce inflammation at extra-oral sites through oro-pharyngeal or oro-digestive translocation, contributing to conditions such as aspiration pneumonia and intestinal dysbiosis, respectively. This elevated systemic inflammation from periodontitis has significant implications for systemic health, potentially contributing to various complications [18].

Periodontal disease is recognized as a risk factor for various systemic conditions. Key pathogens associated with periodontal disease include *P. gingivalis* and *Fusobacterium nucleatum*. In the oral cavity, inflammation caused by *P. gingivalis* can disrupt the intestinal microbial community structure, compromise the intestinal barrier, induce endotoxemia, and trigger a systemic inflammatory response [19, 20]. Under the normal conditions, *F. nucleatum* is rarely found in the intestine. However, it can migrate there, where it inhibits T-cell-mediated immune responses, thereby contributing to the progression of inflammatory bowel disease (IBD) [21]. Additionally, *Streptococcus salivarius,* an early colonizer in the oral cavity, can also establish itself in the intestinal tract. It plays a role in intestinal inflammation and homeostasis by downregulating the nuclear transcription factor NF-κB in small intestinal epithelial cells. These interactions highlight the complex relationship between oral pathogens and intestinal health [22].

Oral squamous cell carcinoma (OSCC) and oropharyngeal cancer (OPC) represent a significant global health challenge, with approximately half a million new cases annually. Tobacco use, areca nut chewing, heavy alcohol consumption, and HPV infection are major risk factors. These cancers often arise from oral potentially malignant disorders (OPMDs), such as leukoplakia and erythroplakia, underscoring the importance of early detection. OSCC commonly presents as persistent ulcers or nodular growths, often accompanied by induration. Early diagnosis through systematic oral examinations can improve survival rates significantly. However, public education, early screening, and professional intervention remain inadequate, particularly in underserved populations. Prevention strategies, including tobacco cessation, HPV vaccination, and lifestyle modifications, are critical in reducing incidence. Advances in molecular diagnostics and web-based learning tools have further enhanced early detection and management capabilities [15].

Oral health is profoundly affected in immunocompromised individuals, particularly those with HIV/AIDS or undergoing immunosuppressive therapy. Common manifestations include oral candidiasis, hairy leukoplakia, severe periodontal disease, and Kaposi's sarcoma. These conditions often correlate with disease progression and serve as diagnostic markers for underlying systemic issues. In the context of HIV/AIDS, anti-retroviral therapy has reduced the prevalence of many oral lesions, though complications such as oral warts persist. Saliva-based diagnostic tools are increasingly used for early HIV detection. Additionally, conditions such as noma, a devastating necrotizing infection, highlight the intersection of oral health with malnutrition and systemic infections, particularly in resource-poor regions [15].

Oral mucosal diseases, including recurrent aphthous stomatitis, lichen planus, and pemphigoid, are often associated with systemic conditions. For instance, lichen planus carries a risk of malignant transformation, while pemphigoid and pemphigus present with mucosal erosions and systemic autoimmune associations. Salivary gland dysfunction, as seen in Sjögren's syndrome, impacts both oral and systemic health, often leading to complications such as lymphoma [15].

Orofacial pain, encompassing conditions such as temporomandibular joint disorders and burning mouth syndrome, presents diagnostic and management challenges due to its multifactorial nature. Proper diagnosis requires distinguishing between dental, neurological, and psychogenic causes. Similarly, orofacial clefts, among the most common congenital anomalies, necessitate multidisciplinary care to address functional and esthetic challenges while improving quality of life [15].

Lesions in the oral cavity and gum disease are often early indicators of systemic diseases such as diabetes, cardiovascular conditions, HIV/AIDS, respiratory diseases, chronic kidney disease, metabolic syndrome, and certain cancers. Conversely, systemic conditions such as diabetes, cardiovascular disease (CVD), and HIV can predispose individuals to more severe periodontal diseases. For instance, oral lesions such as candidiasis or hairy leukoplakia are common in HIV patients and can signal disease progression. Hairy leukoplakia, originally associated with HIV, is now also observed in other immuno-suppressed individuals, such as organ transplant recipients. In diabetes, severe gum disease is a recognized complication, with a bidirectional relationship between periodontitis and glycemic control. Poorly controlled diabetes exacerbates periodontal inflammation through mechanisms involving advanced glycation end products, collagen degradation, and altered immune responses, while periodontal infections can worsen glycemic control, increasing the risk of insulin resistance and pancreatic beta-cell destruction [23].

4. Oral manifestations of medications for systemic conditions

Adverse drug reactions (ADRs) are a critical aspect of pharmacological therapy, defined as harmful or unpleasant responses to medications that may require therapeutic modifications, dosage adjustments, or discontinuation of treatment. A distinction is made between adverse effects (directly attributed to the drug's action) and adverse events (occurring during drug use but not necessarily caused by it). The term "adverse drug event" (ADE) is preferred, encompassing traditional ADRs, side effects associated with proper drug use, and medication errors. Diagnosing these events involves correlating their onset with medication use, excluding other potential causes, and confirming their resolution upon discontinuation of the suspected drug or their recurrence upon rechallenge. Common ADEs include xerostomia, frequently caused by polypharmacy, that significantly impacts quality of life and is associated with drug classes such as antidepressants, antihypertensives, and bronchodilators. Lichenoid reactions, resembling idiopathic lichen planus, are often induced by nonsteroidal anti-inflammatory drugs (NSAIDs) and antihypertensives. Aphthous-like and non-aphthous ulcers, often painful, are linked to therapies with mTOR inhibitors or chemotherapy agents. Bullous disorders and autoimmune dermatological reactions, including Stevens-Johnson syndrome and toxic epidermal necrolysis, though rare, are life-threatening hypersensitivity responses linked to various drugs, including anti-inflammatory and antipsychotic agents. Oral pigmentation can result from the deposition of drug metabolites, such as tetracyclines or antimalarials, while fibrovascular hyperplasia is commonly associated with calcium channel blockers and immunosuppressants. Oral dysesthesias, including altered taste and burning sensations, frequently occur as side effects of chemotherapy and tyrosine kinase inhibitors. Osteonecrosis of the jaw is a severe ADE linked to bisphosphonates and anti-angiogenic agents, particularly in cancer and osteoporosis therapies. Opportunistic infections are common in immunosuppressed patients, while angioedema and malignancy risks are associated with ACE inhibitors, immunomodulators, and various other drug classes. Recognizing, diagnosing, and managing ADEs require careful review of the patient's medical history, correlation with treatment regimens, and a thorough evaluation of the risks and benefits of therapy. This is particularly important in the context of polypharmacy, especially among elderly patients or those with complex chronic conditions [24].

5. The role of the oral microbiome

5.1 Understanding the oral microbiome

The oral cavity is a dynamic microbial ecosystem comprising various substrata and micro-environments that support diverse microbial communities. This environment constantly faces challenges such as dietary influences, salivary flow, masticatory forces, and the introduction of external microbes. The composition of the oral microbiome evolves throughout life, influenced by factors such as host genetics, maternal transmission, dietary habits, oral hygiene practices, medications, and systemic conditions. The human oral cavity hosts over 700 types of microorganisms, making the oral microbiome one of the most important and complex microbial communities in the body. It is also a key focus area of the Human Microbiome Project (HMP), alongside the nasal cavity, vagina, intestine, and skin. Advancements from the Human Microbiome Project have deepened our understanding of oral microbes, extending beyond their roles in caries, periodontal diseases, and other oral conditions to a broader appreciation of their impact on overall health. This ever-changing ecosystem creates opportunities for microbial imbalances, or dysbiosis, which can lead to dental and periodontal diseases. Advances in research, utilizing both *in vitro* and culture-independent methods, have significantly enhanced our understanding of the complex polymicrobial communities in the oral cavity. These approaches have also shed light on the environmental, local, and systemic factors that shape the dynamics of the oral microbiome and its role in oral health and disease. Growing evidence highlights the connection between the oral microbiome and systemic diseases, primarily due to the ability of oral microbes to influence the inflammatory microenvironment. Beyond lifestyle factors such as physical activity, poor oral health is closely linked to an unhealthy body index. Research has shown significant interactions between oral health and the digestive system. For instance, oral microbes can impact the metabolism of butyrate in intestinal microbes, while pathogens associated with periodontitis can enter the bloodstream through inflamed periodontal tissues, enabling their systemic circulation and effects. A notable example is *F. nucleatum,* which has been found to colonize the intestine and contribute to colorectal cancer through bloodborne pathways. Additionally, metabolites produced by oral microorganisms can circulate through the bloodstream, triggering low-grade inflammation that promotes the onset and progression of chronic inflammatory diseases in the digestive system. This perspective, supported by emerging research on the oral microbiome, is increasingly recognized in studies on systemic diseases associated with gut flora imbalances. As such, the role of oral microbes in the digestive tract is likely a critical mechanism by which they influence systemic health [25–28].

Adults produce over 1000 mL of saliva daily, with most of it entering the gastrointestinal tract. This highlights the oral cavity's role as a significant reservoir for intestinal microbes, contributing to the stability of the intestinal microecosystem. However, virulent strains from the oral cavity can migrate to the intestine through the digestive tract or bloodstream, influencing the progression of various intestinal inflammatory diseases. Inflammatory bowel disease (IBD) is a growing global health concern, particularly in the developed countries, with rising prevalence in developing nations as well. In China, the prevalence is approximately 3.44 per 100,000 individuals. While the exact causes of IBD remain unclear, it is thought to result from a combination of genetic and environmental factors. Additionally, the intestinal microbiome plays a crucial role in the disease's development and progression. Recent research has also identified a correlation between oral microbes and IBD, suggesting that oral microbiota may significantly impact intestinal inflammation and disease mechanisms [29].

Extensive research demonstrates that oral microbes significantly influence tumor proliferation, invasion, and metastasis. Oral microorganisms can directly contribute to tumor development through specific cytokines and pathways or indirectly by modulating the immune response between the tumor and the host. These interactions can promote tumor formation, progression, and metastasis. Certain oral microbes implicated in these processes show potential as biomarkers for oral cancer research and early detection of cancer development. A deeper understanding of the mechanisms underlying the interaction between oral microbes and tumors could pave the way for the development of innovative targeted therapies. Such advancements would significantly enhance the diagnosis, treatment, and prognosis of oral cancer patients in the future. Key oral pathogens such as *P. gingivalis, F. nucleatum,* and *Treponema denticola* contribute to OSCC through mechanisms such as promoting inflammation, inhibiting apoptosis, and supporting tumor growth, invasion, and metastasis. Co-infections of *P. gingivalis* and *F. nucleatum* further amplify these effects by activating Toll-like receptor signaling and STAT3 pathways. Poor oral hygiene and periodontal diseases are linked to esophageal squamous cell carcinoma. *T. denticola* and *P. gingivalis* are frequently detected in esophageal tumors, promoting inflammation and carcinogenesis. Salivary microbial changes, such as reduced diversity and altered abundances of specific bacteria like Corynebacterium, may assist in diagnosis. Studies show a higher prevalence of *P. gingivalis* and *Aggregatibacter actinomycetemcomitans* in pancreatic cancer patients. Salivary biomarkers, including altered ratios of Leptotrichia to Porphyromonas, have potential diagnostic value for pancreatic cancer. *F. nucleatum* is strongly associated with colorectal cancer. It promotes tumor growth by binding to cancer cell E-cadherin and suppressing immune cell activity through Fap2, enabling tumor evasion and proliferation. Animal studies confirm its ability to colonize and exacerbate colorectal tumors [26, 28, 30].

Periodontal disease has been identified as a significant risk factor for cardiovascular diseases (CVD), including coronary heart disease, endocarditis, and myocardial infarction. Atherosclerosis (AS), a key pathological process in coronary heart disease, involves lipid deposition in arterial walls, leading to plaque formation and narrowing of blood vessels. Periodontal pathogens such as *P. gingivalis* and their metabolites can enter the bloodstream through damaged periodontal tissue, inducing systemic inflammation and promoting atherosclerotic plaque formation. Clinical studies and animal experiments demonstrate that *P. gingivalis* can alter gut microbiota, cause endotoxemia, and increase systemic inflammatory markers such as C-reactive protein (CRP), IL-1β, IL-6, and TNF-α. These inflammatory responses contribute to vascular endothelial damage and the progression of AS. Additionally, bacteria such as *Streptococcus sanguis* and *Streptococcus gordonii*, commonly found in dental plaque, are linked to infective endocarditis by adhering to thrombus-like protrusions on vascular endothelium. Treatment of periodontitis has been shown to reduce serum CRP levels and systemic inflammation, highlighting the direct relationship between periodontal inflammation and serum inflammatory markers. Periodontitis is also associated with biomarkers such as Galectin-3 and suPAR, which are indicators of heart inflammation and fibrosis. These findings underscore the critical role of periodontal health in predicting and potentially mitigating cardiovascular disease risk [8, 9, 31].

The relationship between oral microbes and Alzheimer's disease (AD) has gained significant attention. Multiple clinical studies suggest an association between periodontitis and cognitive decline. Longitudinal research has linked periodontitis, tooth loss, and poor oral hygiene to increased risks of cognitive impairment and Alzheimer's disease, with shared risk factors such as smoking and low education levels contributing to this connection. However, the exact causal relationship remains unclear [32].

Studies in animal models demonstrate that *P. gingivalis* (a periodontal pathogen) increases brain deposition of amyloid-beta (Aβ), triggers neuroinflammation, and impairs cognitive function. Gingipains, a virulence factor of *P. gingivalis*, are neurotoxic and disrupt neuronal function by damaging Tau proteins. Inhibiting gingipains reduces Aβ production, neuroinflammation, and hippocampal damage, highlighting their potential as therapeutic targets [33].

Diabetes and periodontitis are closely linked, with diabetes increasing the risk of chronic periodontitis by 2–3 times, while periodontitis exacerbates systemic inflammation and impacts blood glucose control. Oral microbes in periodontal pockets interact with the immune system, triggering chronic inflammation and systemic effects. Pathogens like *P. gingivalis* activate inflammatory pathways (e.g., NF-κB), reducing insulin sensitivity, increasing insulin resistance, and disrupting glucose metabolism. Additionally, oxidative stress induced by periodontal pathogens generates reactive oxygen species (ROS), further impairing insulin signaling and promoting systemic inflammation. Periodontal bacteria can enter the bloodstream, causing bacteremia and systemic inflammatory mediator elevation (e.g., C-reactive protein, pentaxin-3). Effective periodontal treatment has been shown to reduce these systemic inflammatory markers, emphasizing the critical role of oral health in managing diabetes and systemic inflammation [34].

Rheumatoid arthritis (RA) and periodontitis share common risk factors, such as smoking and HLA-DRB1 allele polymorphism, as well as similar pathological features, including chronic inflammation and bone resorption mediated by IL-1, TNF-α, and matrix metalloproteinases. Studies suggest oral microbes, particularly *P. gingivalis* and *A. actinomycetemcomitans*, may contribute to RA by inducing citrullination through peptidyl arginine deiminase (PAD) activity, leading to the production of autoantibodies such as anticitrullinated protein antibodies (ACPA). *P. gingivalis* produces bacterial PAD (pPAD), which catalyzes citrullination, while *A. actinomycetemcomitans* triggers neutrophil PAD activity through its LtxA toxin. Both mechanisms result in the formation of self-antigens and RA-associated immune responses. Furthermore, studies indicate differences in the oral microbiome of RA patients compared to healthy individuals, with microbial composition linked to clinical indices. Diagnostic models based on oral and intestinal microbiome data show high specificity and accuracy, highlighting the potential of the oral microbiome as a biomarker for RA progression and prognosis. This suggests a significant role for oral microbes in RA pathology and opens avenues for diagnostic and therapeutic strategies [35].

5.2 Dysbiosis and systemic consequences

Infections anywhere in the body lead to the upregulation of chemokines, cytokines, and other inflammatory mediators, resulting in inflammation. Dental and oral mucosal infections are highly prevalent and often involve chronic microbial infections that initiate inflammation in adjacent tissues. Microorganisms originating from the mouth can spread locally, causing infections in the jaws, facial structures, and parapharyngeal or peritonsillar spaces. In severe cases, the spread can extend intracranially or to the lungs through aspiration, posing life-threatening risks. Beyond direct spread and metastatic extraoral infections, oral infections can also have systemic effects mediated by bacterial metabolites (toxins) and immune responses, such as those seen in *Streptococcus viridans* endocarditis or glomerulonephritis. These infections may also influence blood coagulation and contribute to low-grade systemic inflammation, potentially explaining various organ-level complications. From a broader perspective, studies estimate that at least 20% of small molecules in blood are of microbial origin. The oral cavity, home to thousands of microbial species, presents a significant risk; in individuals with gingivitis, the cumulative area of inflamed tissue is comparable to the size of a human hand. Inflamed periodontal tissues provide direct access for oral microorganisms to enter the lymphatic and circulatory systems, triggering metabolic activation of epithelial cells, B- and T-lymphocytes, and affecting DNA and its repair mechanisms. To address disease-associated dysbiosis in the oral cavity, strategies have been proposed to restore a "healthy" microbiome through the use of probiotics, promoting a beneficial state that may help slow or prevent disease progression [9].

6. Shared risk factors between oral and systemic health

6.1 Lifestyle factors influencing health

The global epidemic of non-communicable diseases (NCDs) has become a significant health and socioeconomic challenge. Conditions such as cardiovascular disease (CVD), diabetes mellitus (DM), cancer, and chronic respiratory diseases account for approximately two-thirds of global mortality. Over time, shared risk factors between NCDs and common oral diseases have been extensively documented. These include excessive sugar consumption, alcohol use, tobacco use, unhealthy diets high in saturated and trans-fats and salt, obesity, stress, depression, genetic predispositions, and socioeconomic determinants. Addressing these modifiable risk factors is essential for integrating oral health into broader health agendas. Population-wide control of these risk factors is critical for preventing diseases, improving patient management, and achieving overall health benefits. A coordinated approach to tackle these shared determinants can lead to significant advancements in public health and well-being [17].

Smoking has long been linked to periodontitis and tooth loss. As early as 1947, researchers identified an association between tobacco smoking and acute necrotizing ulcerative gingivitis. Since then, numerous studies have confirmed the connection between cigarette smoking and common adult forms of periodontitis. Although studies on periodontal risk factors are often influenced by confounding variables such as oral hygiene and dental plaque levels, proper statistical adjustments consistently show that smoking is a significant independent risk factor for periodontal disease. Even light smoking has been shown to increase the risk of periodontitis and alveolar bone loss by four to five times. The oral cavities of tobacco smokers and users of smokeless tobacco are exposed to high concentrations of nicotine, with levels in gingival crevicular fluid reported to be up to 300 times higher than in serum. Nicotine's vasoconstrictive effects are believed to reduce bleeding on probing, a common indicator of periodontal disease, in smokers compared to nonsmokers. However, nicotine adversely affects periodontal health by inhibiting the proliferation and adhesion of human gingival fibroblasts to root surfaces, impairing gingival attachment levels. Additionally, nicotine promotes osteoclast growth and activity, accelerating alveolar bone loss. It also increases the expression of advanced glycation end products and their receptors in periodontal tissues, which can negatively impact the success of periodontal surgical treatments in smokers [36].

Stress, a psycho-physiological response to stimuli, plays a crucial role in survival, preparing the body to respond to acute challenges like infection or surgery through mechanisms such as immune cell redistribution, increased alertness, and energy redirection. While acute stress can enhance immunity, chronic stress disrupts immune function, leading to potentially harmful imbalances. Stress can arise from physical causes, such as diseases, or psychological factors, including major life events or daily stressors. Prolonged stress may result in anxiety, depression, impaired cognition, or altered self-esteem, with individual coping mechanisms, social support, and lifestyle factors influencing the impact of stress [37]. In modern society, the role of stress and its effects on the body have evolved. Once a protective mechanism to help the body adapt to challenges, stress responses now often exceed coping thresholds, leading to detrimental health effects. The diseases linked to these stress reactions underscore the complex interplay between physical, psychological, and social factors in health and illness. This shift highlights the critical need for a multidisciplinary approach to the evaluation and treatment of stress-related conditions. Advances in the study of stress have been significantly enhanced by quantitative and qualitative analyses of saliva, providing valuable insights into stress mechanisms and their impacts on the body [38]. Studies consistently highlight a positive correlation between stress and periodontal disease. Chronic stress, measured through self-report scales or biomarkers like cortisol, has been associated with clinical attachment loss, increased probing depth, and alveolar bone loss. Financial strain and depression further increase the risk of periodontal disease progression, as seen in large population studies. Depression has also been linked to elevated serum IgG levels against *Tannerella forsythia* and greater periodontal deterioration over time. These findings underscore the importance of addressing psychological factors and stress management in periodontal disease prevention and treatment [39].

Periodontal disease involves bone and attachment loss triggered by bacterial biofilm in a susceptible host, with factors like stress playing a significant role in disease progression. Evidence links elevated cortisol levels, a biomarker of psychological and physical stress, to deeper probing pocket depths, attachment loss, and increased risk of periodontitis. Cortisol-induced shifts in immune response and microbiome gene expression further promote periodontal disease progression. Elevated glucocorticoid levels also contribute to systemic bone loss by impairing osteoblast activity, enhancing osteoclast genesis, and disrupting calcium metabolism, with similar mechanisms affecting periodontal tissues. Stress-related disorders exacerbate these effects, as shown by positive correlations between cortisol levels, stress scores, and periodontal inflammation. The integration of glucocorticoid assessment into biomarker profiling offers potential for personalized strategies in diagnosing and treating periodontal disease, emphasizing the interplay between stress, immune modulation, microbiome dynamics, and bone homeostasis [40].

Alcohol abuse has been identified as a common risk factor affecting both oral and general health. Individuals with high alcohol consumption have been found to have significantly more decayed tooth surfaces and periapical lesions [41].

6.2 Socioeconomic and behavioral determinants

The WHO conceptual framework for action on the social determinants of health emphasizes the impact of structural determinants, such as economic, social, and welfare policies, in shaping social hierarchies and influencing individual socioeconomic status. This status, in turn, affects health outcomes through living, working, and aging conditions, as well as risks for disease. Key intermediate determinants include housing, working conditions, social capital, psychosocial factors such as stress and social support, and access to health care. Despite longstanding recognition of the social determinants of health, progress in implementing policies to address these factors has been limited. In dental public health, there has been advocacy for integrated, upstream, community-based approaches. However, oral health care and disease prevention continue to operate largely in isolated silos. Dental policy often relies on simplistic, downstream interventions due to the dominance of a clinical interventionist philosophy and challenges in generating evidence for upstream approaches. This biomedical focus favors clinical preventive measures and chairside advice over comprehensive, population-level strategies. Several models have adapted the WHO social determinants framework specifically for oral health. Increasing awareness exists around the need to shift from clinical approaches to structural policies addressing oral health inequalities. These policies should focus on social determinants and shared risk factors, such as excessive sugar consumption, tobacco use, and alcohol intake, alongside their broader socioeconomic drivers. Globally, sucrose production has risen steadily since the 1980s, making sugar the most widely available sweetener. This trend has led to increased sugar consumption and a corresponding rise in dental caries, particularly in low- and middle-income countries (LMICs). Economic development in these regions has lifted millions out of poverty but also driven rapid demographic and nutritional transitions characterized by adverse dietary changes, reduced physical activity, and deteriorating health. Multinational corporations have expanded into emerging economies, targeting markets with high-sugar foods and drinks. This shift in consumer behavior has exacerbated the prevalence of non-communicable diseases, including oral diseases, highlighting the urgent need for structural interventions to address these shared challenges [42].

As health systems undergo transformation, increasing focus is being placed on access, utilization, and quality of care, and their effects on population health. Simultaneously, research has highlighted the critical role of social determinants of health (SDH) such as poverty, education, and the physical environment in shaping health outcomes. Reports like the World Health Organization's 2008 Commission on Social Determinants of Health and the UK's 2010 Marmot Report have demonstrated the strong connection between socioeconomic factors, daily living conditions, and a social gradient in health. These determinants influence exposure to health-promoting or health-damaging conditions, with impacts that can accumulate over a lifetime, shape health trajectories, and even be transmitted across generations [43].

Despite recognition of the multidimensional nature of SDH, efforts to address them have traditionally been siloed within health systems, often neglecting contributions from sectors such as education, economics, and the environment. A multisector approach is urgently needed, and dentistry is no exception. Oral health is deeply intertwined with SDH, sharing common risk factors with major noncommunicable diseases (NCDs) such as heart disease, diabetes, cancer, and stroke. Socioeconomic status, encompassing family income, education, employment, and housing, significantly affects oral health, with poorer communities experiencing worse outcomes, particularly among children and the elderly. This understanding has led to the development of the Common Risk Factor Approach (CRFA), which integrates oral health into broader public health strategies by addressing shared risk factors across NCDs. Disparities in oral health are evident globally, particularly in rates of caries, periodontitis, head and neck cancers, tooth loss, and access to preventive care. These disparities, closely linked to SDH, demand urgent policy action to address their root causes. Emphasizing translational research and public health strategies can help tackle these inequalities and improve oral health outcomes worldwide [43].

The environment plays a critical role in determining health outcomes, encompassing both social and built environments. Social determinants such as income inequality, social support, and racial discrimination, along with built environments shaped by human activities, profoundly influence health. In oral health, conditions such as dental caries and fluorosis are strongly tied to environmental factors like water fluoridation. Dental caries, one of the most prevalent chronic diseases globally, disproportionately affects disadvantaged populations, particularly children from ethnic minorities, rural areas, and lower socioeconomic backgrounds. Evidence supports the use of fluoridated water and fluoride products to reduce caries in underserved communities, emphasizing the need for equitable public health interventions. Climate change further exacerbates health inequalities through its direct and indirect impacts. Extreme weather events, food and water insecurity, and vector-borne diseases highlight the interconnectedness of environmental shifts and systemic health issues. Vulnerable populations bear a disproportionate burden, facing barriers to healthcare access and worsening social inequalities. Climate change threatens progress in global health and poverty reduction by pushing millions into poverty annually, emphasizing the urgency of comprehensive, multisectoral responses. Addressing these challenges requires policies to reduce carbon emissions, stabilize climate conditions, and establish resilient public health systems. Multidisciplinary approaches are essential, incorporating local communities, governments, and international collaborations. Research underscores the growing interdependence of environmental and human well-being, revealing associations between climate factors and a broad spectrum of health outcomes, including respiratory and cardiovascular diseases, undernutrition, and mental health disorders. Sustainable development, defined by economic growth, social inclusion, and environmental protection, is a cornerstone of addressing these health determinants. The United Nations' 17 Sustainable Development Goals (SDGs) for 2030 provide a roadmap for achieving equitable and sustainable progress. Goals include eradicating poverty and hunger, ensuring universal access to education, healthcare, and clean water, and promoting gender equality, environmental conservation, and climate action. These integrated objectives align with the need to address oral health disparities and systemic diseases, emphasizing the mutual reinforcement of sustainable development and global health equity [44].

7. The impact of oral health on quality of life

Health-related quality of life (HRQoL) is a complex, multidimensional concept encompassing physical, cognitive, emotional, and social aspects, influenced by health imbalances such as diseases or injuries. Since its emergence in the 1980s, HRQoL has been increasingly recognized for its sensitivity to symptoms and treatment effects. Both general and specific approaches, such as oral health assessments, have been developed to evaluate HRQoL. The Oral Health Impact Profile (OHIP), based on Locker's model, is a widely used instrument that examines physical, psychological, and social domains to quantify the impact of oral health issues on general health [45]. To better understand individuals' perceptions and experiences regarding their oral health, patient-centered outcome measures have become increasingly popular. These tools guide the treatment of oral conditions and the rehabilitation of tooth loss by incorporating patients' perspectives. Among the various instruments developed to assess OHRQoL, the 14-item Oral Health Impact Profile (OHIP-14) is the most widely used, particularly for evaluating the effects of oral health on the quality of life in adults and older populations [46].

Oral health is a vital component of overall health and quality of life (QoL), yet it often remains a low priority in healthcare policies despite its profound impact. Common oral conditions like caries and periodontitis are widespread chronic co-morbidities linked to risk behaviors such as smoking, alcohol use, and poor diet, and they significantly contribute to the global burden of chronic diseases. These issues disproportionately affect vulnerable populations due to the high costs of treatment, exacerbating healthcare inequalities. Although the World Health Organization (WHO) recognizes health as a human right and oral health is included in many national health plans, preventable and treatable oral diseases continue to negatively impact QoL. This underscores the urgent need for integrated, cost-effective care models and a greater emphasis on measuring the broader effects of oral health on individuals' lives [47].

Oral health problems, while not typically life-threatening, represent a significant public health concern due to their high prevalence and substantial social, economic, and psychological impacts. These issues influence an individual's quality of life, underscoring the recognition of oral health as a vital component of general health and well-being by the WHO in its Global Oral Health Program. The concept of oral health-related quality of life (OHRQoL) reflects the impact of oral conditions on daily functioning and encompasses broader dimensions beyond physical health. OHRQoL is increasingly emphasized in clinical dentistry through a patient-centered biopsychosocial approach, recognizing the patient's role in treatment and the necessity for evidence-based care. It is also pivotal in dental research and education, highlighting the profound impact of periodontal disease on quality of life. Using OHRQoL as a metric helps communicate the severity of dental issues to policymakers, aiding in the formulation of healthcare strategies, policies, and funding decisions. It has been integrated into major health policy, further solidifying its importance in oral and general health frameworks [48].

8. Toward a preventive and collaborative approach

The adage, "Listen to your patient, they are telling you the diagnosis," highlights the critical role of effective communication in achieving an accurate diagnosis. Comprehensive history-taking forms the foundation of this process and requires careful listening and active engagement between the physician and patient. A detailed medical history should encompass past and present illnesses, adverse allergic reactions, surgeries, medication use, family medical history, and personal habits related to oral hygiene, tobacco use, and alcohol consumption. Recording the patient's chief complaint, along with associated symptoms, is essential and should be done attentively, without interruption. It is equally important to explore psychological factors, such as stress or emotional challenges, that may be contributing to the patient's condition. Patients should feel reassured that the physician is committed to addressing their concerns and managing the disease effectively. However, diagnosing becomes more complex when patients present with multiple complaints. In such cases, open-ended conversations, active listening, and empathetic affirmations can help unravel the patient's experience, concerns, and the broader impact of the illness on their general health and daily functioning [49].

Many physicians often neglect to perform clinical examinations of the oral cavity during patient visits. Additionally, their knowledge and training regarding oral health are often inadequate. Consequently, patients with oral health issues are frequently not referred to dental professionals, leading to unmet dental care needs, worsening oral health problems, increased healthcare costs, and negative outcomes for patients. This lack of coordination can also result in fragmented care, where healthcare providers focus solely on their specialties, overlooking other health concerns. To address this, physicians should be equipped with the knowledge and skills to identify oral health problems and refer patients to dental professionals. Implementing an automated referral system could streamline this process, improving communication between physicians and dentists while enhancing the quality of care for patients. Likewise, dentists can contribute by offering preventive medical services, such as monitoring blood pressure and screening for diabetes. Dental professionals should also educate patients about the risks of tobacco use, provide smoking cessation tools, and refer patients to appropriate specialists when needed. Regular dental screenings can help identify early signs of systemic conditions, facilitating timely referrals to physicians. A collaborative, inter-professional approach to care ensures comprehensive treatment, improves overall patient health, and reduces healthcare costs, promoting better outcomes for all. Collaborative engagement among healthcare providers, particularly for at-risk populations, is crucial. Recognizing shared social determinants of health and utilizing integrated electronic health records create opportunities for better coordination of care. Ongoing communication between medical and dental providers is essential to ensure the implementation of established preventive measures, such as adequate fluoride exposure, healthy dietary practices, beneficial habits, and timely care-seeking behavior in children. In today's complex and frequently shifting landscape of health coverage, effective collaboration between medical and dental professionals is necessary to monitor and improve access to respective services. Maintaining a healthy oral cavity is essential for overall systemic health [50].

Preventing oral and systemic diseases starts with educating patients about their interconnectedness. For instance, patients should be informed that periodontitis is a risk factor for cardiovascular disease (CVD), and individuals with diabetes are at a higher risk for periodontitis, which can make glycemic control more challenging. Encouraging patients to adopt healthier lifestyle behaviors is crucial. Recommendations include smoking cessation, having a balanced diet, regular exercise, and maintaining proper oral hygiene. Patients should brush their teeth at least twice daily and floss once a day to clean areas that brushing cannot reach. Using an antimicrobial mouthwash may also be beneficial for some individuals. Regular professional dental cleanings are vital, as only a dentist can remove calculus that harbors bacterial biofilm along the gum line. Patients who have not seen a dentist in over a year should be encouraged to schedule an appointment. Diabetic patients should undergo comprehensive oral exams, including periodontal assessments. Patients should be advised to seek dental care if they notice symptoms such as red, swollen gums, gum pockets, pus between teeth and gums, loose teeth, changes in their bite, or persistent bad breath. Missing teeth should be replaced to ensure proper chewing for adequate nutrition, and patients should stay hydrated to prevent dry mouth. Additionally, patients should inform their dentist about any new health conditions or changes in their medications to ensure holistic and effective care [51, 52].

9. Conclusions

In conclusion, addressing the complex interplay between oral and systemic health requires a shift toward integrative, preventive, and patient-centered approaches. By recognizing the shared risk factors and bidirectional relationships between oral diseases and systemic conditions, healthcare systems can prioritize strategies that bridge the gap between dentistry and general medicine. Emphasizing interdisciplinary collaboration, enhancing access to care, and fostering patient education will not only mitigate health disparities but also improve outcomes across populations. The development of evidence-based protocols, combined with innovations in technology such as automated referral systems and integrated health records, can streamline care delivery and facilitate early detection of systemic diseases through oral health evaluations. Ultimately, the integration of oral health into public health frameworks is crucial for advancing holistic well-being and reducing the burden of chronic conditions on individuals and healthcare systems worldwide.

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Conflict of interest

The authors declare no conflict of interest.

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Chapter 2

Oral Health Promotion and Integration with Systemic Health: Best Practices, Innovations, and Community Approaches

Najat A. Alyafei

Abstract

This chapter delves into the vital role of oral health in overall systemic wellness, illustrating how community-driven oral health programs and preventive practices impact broader health outcomes. By integrating oral health with systemic health frameworks, this approach aligns with managing noncommunicable diseases (NCDs) like diabetes and cardiovascular conditions. Key case studies, such as Brazil's Smiling Brazil and Qatar's Asnani School Oral Health Program, demonstrate the effectiveness of preventive strategies, while innovations like laser therapies and tele-dentistry reveal the transformative potential of modern dental technology. The chapter also addresses the critical intersection of mental health and oral health, promoting interdisciplinary collaboration to enhance the patient outcomes and support healthier communities.

Keywords: oral health promotion, preventive dentistry, health integration, community health programs, noncommunicable diseases

1. Introduction

Oral health is integral to overall well-being, significantly influencing systemic health, productivity, and quality of life. Traditionally, global efforts have centered on curative treatments; however, this document explores the transformative potential of preventive and community-driven approaches in addressing oral health disparities and improving population health [1]. By synthesizing evidence-based strategies and comprehensive case studies, it highlights innovative programs such as Brazil's Smiling Brazil and Qatar's Asnani School Oral Health Program (Arabic for "my teeth"), which have successfully integrated systemic health and achieved sustainable outcomes [2].

This chapter uniquely adopts an interdisciplinary lens, connecting oral health to noncommunicable diseases (NCDs), mental health, and emerging technologies. It emphasizes culturally tailored interventions, showcasing Qatar's integration of traditional practices, such as the use of the miswak, with modern preventive dentistry.

In doing so, it offers a roadmap for policymakers, healthcare providers, and educators to implement scalable and sustainable solutions across diverse populations.

The chapter also addresses the critical gap in geriatric oral health, particularly in the Arabian Gulf region, where oral health remains underrepresented despite significant progress in elderly care. Aging populations face unique challenges, including reduced salivary flow, tooth loss, and periodontal diseases, which adversely impact nutrition, systemic diseases, and quality of life. Integrating oral health into comprehensive geriatric care frameworks can play a critical role in promoting healthy aging and improving the quality of life.

Globally, the population of individuals aged 60 years and older is projected to increase from over 703 million (9%) in 2020 to 1.5 billion (16%) by 2050. The majority of these older adults (>80%) will reside in low- and middle-income countries (LMICs). This aging trend is associated with physiological changes, such as reduced salivary flow, leading to difficulties in chewing and swallowing, which negatively impacts nutrition and quality of life. Poor oral health, including periodontal disease and tooth loss, exacerbates these issues, underscoring the importance of integrating oral health into broader aging care strategies [3].

The Arab region, in particular, is experiencing a significant demographic transition, with life expectancy increasing and mortality rates decreasing. The population of older adults is projected to double by 2030, reaching nearly 50 million. This trend highlights the urgent need for healthcare systems in the region to adapt to the growing demands of aging populations. By incorporating oral health into systemic health initiatives, healthcare providers can address the specific needs of older adults, fostering healthier aging and improved overall quality of life [3].

Far from being a mere review, this chapter is a call to action. It combines policy analysis, clinical innovation, and community engagement to fill a crucial gap in the literature, providing practical frameworks and data-driven recommendations to advance oral health promotion globally.

2. Fluoride treatments

2.1 Efficacy of fluoride treatments

Fluoride is a cornerstone of caries prevention, with its effectiveness demonstrated through both systemic and topical applications. Community water fluoridation has reduced dental caries prevalence by approximately 25% in children and adults, according to the Centers for Disease Control and Prevention [4]. Topical fluoride applications, such as varnishes and gels, enhance enamel remineralization, providing a protective barrier against acid attacks.

A Cochrane review found that fluoride varnishes, applied two to four times annually, reduce caries in primary teeth by 43% and permanent teeth by 37% [5]. These results emphasize the importance of fluoride treatments as a cost-effective, evidence-based preventive measure, particularly in the underserved communities where access to dental care is limited.

- Mechanism of action:

  Fluoride impedes enamel demineralization while promoting remineralization, which strengthens teeth and prevents decay.

It integrates into the tooth structure, enhancing resistance to acid erosion and microbial attacks.

- Impact on public health:

  Community water fluoridation has been shown to reduce decayed, missing, and filled teeth (DMFT) in children by 26% and adults by 35% [6].

  The program increases the proportion of caries-free children by 14–15%, demonstrating its broad preventive impact.

2.2 Long-term impact of dental sealants

Dental sealants provide an additional layer of protection for molars, where most caries occur. These thin, protective coatings prevent food and bacteria from accumulating in the grooves of teeth, thereby reducing caries risk.

Studies highlight those children receiving sealants experienced a 60% reduction in caries during the first year, with continued benefits lasting up to 4 years. Sealants are particularly effective in protecting vulnerable populations, including children in underserved areas.

- Public health applications:

  School-based dental sealant programs have proven successful in preventing caries and improving oral health equity [7].

  Sealants contribute to long-term savings in healthcare costs by reducing the need for restorative treatments.

2.3 Dietary counseling as a preventive strategy

Dietary counseling is another pivotal strategy for reducing caries risk. Excessive sugar consumption remains a primary driver of dental caries. Collaborative efforts between dental professionals and nutritionists are vital for promoting healthier dietary choices and reducing sugar intake.

It is found that limiting free sugar intake to less than 10% of total energy consumption significantly decreases caries risk [8]. Educational programs targeting children and their caregivers can instill lifelong habits that support both oral and systemic health [9].

- Key components of counseling:

  Educating individuals on the effects of sugar on dental health.

  Promoting the consumption of foods rich in nutrients that support enamel strength, such as calcium and phosphorus.

  Encouraging frequent water intake to reduce plaque buildup and enhance oral hygiene.

3. The intersection of oral health and noncommunicable diseases

Oral health and noncommunicable diseases (NCDs) such as diabetes, cardio-vascular conditions, and respiratory diseases share a bidirectional relationship. Emerging evidence highlights the role of oral health as both an indicator and a contributor to systemic health outcomes, underscoring the need for integrated care approaches [10].

3.1 Bidirectional relationship between oral and systemic health

Oral health is not only influenced by but also significantly contributes to systemic health outcomes. Poor oral health has been closely linked to systemic diseases such as diabetes, cardiovascular conditions, and aspiration pneumonia. Emerging research shows that periodontitis exacerbates systemic inflammation through pathways involving cytokines such as interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF-α), both of which are common mediators in chronic diseases. Additionally, poor oral health affects nutritional intake, self-perception, and quality of life, further compounding health outcomes.

- *Diabetes and periodontal disease*: Periodontal disease exacerbates systemic inflammation, worsening glycemic control in diabetic patients. Studies show that effective periodontal treatment can reduce HbA1c levels by up to 0.4%, improving diabetes management [11].

- *Cardiovascular diseases*: Chronic periodontal inflammation contributes to systemic inflammatory markers such as IL-6 and TNF-α, increasing the risk of atherosclerosis and other cardiovascular conditions. Oral bacteria such as *Porphyromonas gingivalis* have been identified in arterial plaques, suggesting direct bacterial involvement in cardiovascular pathology.

- *Periodontal disease and aspiration pneumonia*: Older adults with periodontitis have an increased risk of aspiration pneumonia, often resulting in hospitalization or mortalities. This highlights the critical importance of maintaining oral health to prevent severe systemic complications.

- *Oral health as a marker of systemic health*: Conditions such as hyposalivation and tooth loss directly impact dietary choices and digestion, contributing to frailty and dependency in aging populations. These effects demonstrate how oral health serves as both a contributor to and an indicator of systemic well-being.

3.2 Shared risk factors

NCDs and oral diseases share common modifiable risk factors [10]:

- *Tobacco use*: Increases the risk of oral cancer, periodontal disease, and cardiovascular conditions.

- *Unhealthy diets*: High sugar consumption contributes to caries and systemic diseases like obesity and diabetes.

- *Physical inactivity*: Impacts overall health, including susceptibility to periodontal diseases.

Tackling these shared risks allows public health interventions to effectively reduce the burden of both NCDs and oral diseases.

3.3 Role of inflammation in disease progression

Inflammatory pathways serve as a key link between periodontal disease and systemic conditions:

- *Cytokines*: Pro-inflammatory markers such as IL-6 and TNF-α exacerbate systemic inflammation, worsening conditions such as diabetes and cardiovascular diseases.

- *Oral pathogens*: The dissemination of pathogens from periodontal infections into systemic circulation triggers immune responses, further amplifying inflammations.

3.4 Economic and public health implications

Oral diseases impose a significant economic burden worldwide, contributing to over $500 billion annually in healthcare costs and productivity losses [12]. These costs stem from direct expenses, such as treatment and care, and indirect losses due to reduced work productivity and quality of life. Despite the high economic impact, oral health is often underrepresented in public health strategies. Addressing this gap through integrated healthcare models can lead to substantial cost savings and improved outcomes.

3.5 Cost-effective integration

Integrated healthcare models that incorporate oral health services within broader frameworks for managing noncommunicable diseases (NCDs) can significantly reduce the financial burden of advanced oral and systemic health complications.

By addressing oral health early through preventive care and timely interventions, healthcare systems can:

- Minimize costly treatments for advanced periodontal disease, tooth loss, and other complications.

- Reduce the exacerbation of systemic diseases linked to poor oral health, such as diabetes and cardiovascular conditions.

- Improve overall health outcomes, decreasing the need for complex medical interventions and hospitalizations.

Preventive strategies, such as community-based oral health programs, regular screenings, and early treatments, not only reduce costs but also enhance the efficiency and sustainability of healthcare systems [13]. This approach highlights the dual benefits of improving individual health outcomes while alleviating the economic strain on healthcare systems globally.

3.6 Integrated approaches to care

Addressing the intersection of oral and systemic health requires collaborative, multidisciplinary strategies:

- *Interdisciplinary collaboration*: Dentists, primary care physicians, and specialists work together to provide comprehensive care.
- *Integrated screening programs*: Incorporating oral health assessments into routine NCD screenings can aid early detection and management.
- *Geriatric care models*: Innovative approaches for older populations, such as co-managing oral and systemic health issues through interdisciplinary teams, are particularly effective. Training non-dental healthcare providers to screen for oral health conditions in community and aged care settings can bridge gaps in care delivery [14].
- *Community-based initiatives*: Public health programs such as the Home Oral Health Services Program demonstrate the effectiveness of integrated approaches in addressing oral and systemic health simultaneously [13].

3.6.1 Effective interventions and models

Examples of successful oral health programs include [15]:

- *Australia's National Oral Health Plan (2015–2024)*: Mandates oral health check-ups every 2 years and includes oral health risk assessments as part of general health evaluations [15].
- *New Zealand's Strategic Vision for Oral Health (2006)*: Focuses on developing workforce capacity and creating tailored strategies for independent, moderately dependent, and highly dependent older adults [15].
- *Jamaica's Oral Health Policies (2011)*: Highlights preventive measures such as fluoride varnish applications and dental sealants, emphasizing affordability and accessibility.

Such programs demonstrate the effectiveness of integrating oral health into national health strategies.

3.7 Challenges in oral health for older adults

Older adults face numerous challenges in maintaining oral health, which significantly impacts their overall health and quality of life. These challenges arise from the burden of chronic diseases, fragmented care systems, and systemic barriers to accessing necessary dental services.

3.7.1 Burden of non-communicable diseases (NCDs)

Non-communicable diseases (NCDs), including hypertension, diabetes, and cardiovascular conditions, are the leading causes of morbidity and mortality among older adults in the Arab region. Poor oral health, particularly periodontal disease, contributes to systemic inflammation, exacerbating these chronic conditions. For instance:

- Periodontal disease negatively impacts glycemic control in diabetic patients, making diabetes management more difficult.

- Oral pathogens, such as *Porphyromonas gingivalis*, contribute to cardiovascular diseases by promoting systemic inflammation and increasing the risk of atherosclerosis.

Addressing oral health as part of NCD management is crucial for improving overall health outcomes in older populations. By integrating oral health into broader NCD care strategies, healthcare systems can mitigate the compounding effects of these chronic conditions on older adults.

3.7.2 Fragmentation of care

Healthcare systems in the region often operate within disease-specific silos, failing to address the complex and interconnected health needs of older adults. This fragmentation means that oral health services are frequently excluded from routine geriatric care, despite the significant role oral health plays in systemic diseases such as diabetes and cardiovascular conditions.

To overcome this challenge:

- Oral health assessments must be embedded into comprehensive geriatric care frameworks.

- Collaborative care models should involve dentists, primary care physicians, and other healthcare providers to ensure a holistic approach to managing the health of older adults.

3.7.3 Barriers to oral health care

Older adults face numerous barriers to accessing oral healthcare, including:

- *Limited availability of providers*: A shortage of professional oral healthcare providers trained to address the needs of geriatric populations exacerbates the issue.

- *Lack of recognition for geriatric dentistry*: Geriatric dentistry is not recognized as a specialty in many countries, limiting the availability of targeted care [16].

- *Financial and logistical challenges*: Many older adults, particularly in low- and middle-income countries (LMICs), face significant challenges related to the affordability of care and physical access to dental clinics.

Efforts to address these barriers should include:

- *Workforce development:* Expanding the capacity of the oral healthcare workforce through training programs focused on geriatric dentistry.

- *Community-based initiatives:* Establishing programs that deliver affordable, accessible dental care for older adults in their communities.

- *Policy integration:* Including oral health services in public health policies and initiatives aimed at improving healthcare for older adults.

4. Role of mental health in oral health outcomes

Mental health conditions, including depression, anxiety, and stress, significantly impact oral health behaviors and outcomes. The bidirectional relationship between mental and oral health highlights the need for integrated care strategies to achieve improved overall health.

4.1 Impact of mental health on oral health

- *Neglect of oral hygiene:*

  Individuals with depression often neglect oral hygiene practices, leading to an increased risk of dental caries and periodontal diseases.

  Anxiety may result in avoidance of dental visits, delaying treatment, and exacerbating oral health conditions.

- *Stress-related conditions:*

  Stress is associated with bruxism (teeth grinding) and temporomandibular joint (TMJ) disorders, which can cause pain, tooth wear, and jaw dysfunction.

  Chronic stress may also reduce salivary flow, resulting in xerostomia (dry mouth) and increasing susceptibility to caries and oral infections.

4.2 The role of medications

- Many medications used to manage mental health conditions, such as antidepressants and anxiolytics, cause xerostomia as a side effect.

- Reduced salivary flow exacerbates oral health issues by impairing the mouth's natural ability to neutralize acids, remineralize teeth, and fight microbial infections.

4.3 Oral health's impact on mental health

- *Psychosocial consequences:*

  Poor oral health, including tooth loss and halitosis, can lead to reduced self-esteem, social withdrawal, and negative impacts on mental well-being.

  Persistent oral pain and untreated conditions further compound stress and anxiety, creating a cyclical relationship between oral and mental health.

4.4 Integrated care for mental and oral health

- *Supportive dental environments:*

  Providing a non-judgmental and patient-centered atmosphere encourages individuals with mental health conditions to seek care.

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- Techniques such as motivational interviewing and behavioral counseling can help patients overcome dental anxiety and adhere to oral health practices.

  Tailored interventions:

- Specialized oral hygiene instructions and personalized care plans are effective in addressing the unique needs of individuals with mental health conditions.

- Collaboration between dental professionals and mental health providers enhances patient outcomes, fostering a holistic approach to care.

  Educational programs:

- Educating caregivers and patients about the relationship between mental health and oral health promotes better understanding and adherence to preventive practices.

4.5 Public health strategies

Public health initiatives should integrate oral health education into mental health programs, focusing on:

- Raising awareness about the impact of mental health on oral hygiene.

- Encouraging regular dental visits as part of comprehensive mental health care.

- Implementing community-based interventions targeting vulnerable populations.

5. Innovative treatments and technologies in oral health care

Advancements in dental technology have revolutionized oral health care, offering innovative solutions for prevention, diagnosis, and treatment. These innovations not only improve patient outcomes but also enhance the accessibility and efficiency of dental services.

5.1 Laser therapies

- Applications:

  Laser technology is increasingly used in procedures such as periodontal therapy, caries removal, and soft-tissue surgeries.

  It provides a minimally invasive approach, reducing discomfort, bleeding, and healing time for patients.

- Clinical benefits:

  Studies have shown that laser-assisted periodontal therapy effectively reduces the pocket depths and bacterial loads, improving overall oral health.

  Laser treatments minimize damage to surrounding tissues, enhancing precision and patient satisfaction.

5.2 Regenerative dentistry

- Stem cell applications:

  Regenerative dentistry focuses on restoring damaged tissues using biological approaches such as stem cell therapy.

  Stem cells derived from dental pulp or other sources are being explored for regenerating dentin, enamel, and even whole teeth.

- Tissue engineering:

  Guided tissue regeneration techniques utilize membranes and growth factors to repair periodontal and bone defects.

- Future implications:

  Regenerative dentistry offers the potential to address the root causes of oral health issues, transforming how conditions are managed by moving beyond symptomatic treatments.

5.3 Teledentistry

- Overview:

  Teledentistry employs digital communication tools to provide remote consultations, education, and follow-ups.

- Applications:

  It enhances access to dental care in underserved or remote areas.

  During the COVID-19 pandemic, teledentistry played a critical role in ensuring continuity of care while minimizing in-person visits [17].

- Integration with digital tools:

  Platforms combining teledentistry with electronic health records (EHRs) and mobile apps streamline patient monitoring and data sharing.

- Future prospects:

  The integration of artificial intelligence (AI) with teledentistry is expected to further improve diagnostic accuracy and patient engagement [18, 19].

5.4 Digital dentistry

- *Computer-aided design and manufacturing (CAD/CAM)* [17, 18]:

  CAD/CAM technology enables the rapid design and fabrication of dental restorations, such as crowns, bridges, and veneers.

These technologies enhance the precision and efficiency of restorative procedures.

- *3D printing:*

  3D printing is transforming dental prosthetics and orthodontics by producing custom appliances, implants, and surgical guides with unprecedented accuracies.

- *Benefits for patients:*

  Digital workflows reduce chair time and improve the accuracy of dental procedures, enhancing patient comfort and outcomes [20].

5.5 Salivary diagnostics

- *Diagnostic potential:*

  Saliva-based tests offer a non-invasive method for detecting biomarkers associated with systemic diseases such as diabetes and cardiovascular conditions.

  Advances in salivary diagnostics enable early identification of oral and systemic health issues, facilitating timely interventions.

- *Qatar's research efforts:*

  Significant strides in salivary diagnostics are being made in Qatar, with researchers pioneering the characterization of the salivary microbiome and hypertension in the Qatari population [21]. These findings lay the groundwork for future applications in precision oral health care.

5.6 Emerging interventions

Innovative oral health interventions for older adults include [20]:

- Use of ultrasonic devices for denture cleaning.
- Application of fluoride varnish and chlorhexidine rinses to prevent caries and manage oral infections.
- Mobile health technologies for remote oral health education and self-care.

5.7 Innovative solutions and policy recommendations

- *Promotive and preventive care*: A life-course perspective is essential in healthcare planning, with oral health promotion beginning early and preventive care continuing into old age. Providing health education, access to oral care tools, and regular dental checkups for older adults can prevent complications and enhance well-being.
- *Home-based and community care*: Home-based care models, aligned with the strong cultural norms of family-centered care in the Arab region, provide an

effective avenue for integrating oral health education and preventive services. Community and faith-based organizations can further enhance the reach and impact of these programs.

- *Workforce development*: Training primary care physicians, geriatric specialists, and caregivers in oral health care is critical. Equipping healthcare providers with the knowledge to address oral health needs improves early detection and management, reducing long-term complications.

- *Cultural sensitivities*: Tailoring oral health interventions to align with cultural norms in the Arab region enhances acceptance and participation. For example, incorporating traditional values of family support into program design can strengthen care delivery.

6. Global and local case studies

Case studies from around the world illustrate the effectiveness of innovative and community-focused oral health programs. These initiatives provide valuable insights into strategies for improving population-level oral health outcomes.

6.1 Global oral health policies

6.1.1 Saudi Arabia

- Saudi Arabia has implemented progressive oral health policies, including sugar reduction strategies and prenatal oral health education initiatives. These efforts align with the GCC Oral Health Unified Week, promoting dental health across various age groups.

- The inclusion of oral health within universal healthcare coverage, particularly for young children, demonstrates a commitment to integrating oral health into broader public health strategies.

6.1.2 Canada

- The Canadian government has introduced the Canadian Dental Care Plan (2024), expanding access to dental services for uninsured populations. The initiative builds on the interim Canada Dental Benefit for Children Under 12, focusing on underserved communities.

- Mobile dental clinics have been utilized to deliver preventive and restorative care for seniors in long-term care facilities, ensuring access for vulnerable populations.

6.1.3 Denmark

- Denmark leads in integrating oral health into elder care through home-based services, focusing on preventive and therapeutic care for individuals with limited mobility.

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- The country also emphasizes fluoride product provision and oral health promotion as part of a comprehensive public health strategy, aligning with its sugar reduction policies.

6.1.4 Thailand

- Thailand's National Oral Health Plan for the Elders (2016–2022) is a significant initiative under its broader National Health Development Strategic Plan for the Elderly (2013–2023). This plan prioritizes preventive care and integrates oral health services within its universal health coverage framework.

6.2 Comparative insights

- Countries such as Denmark and Thailand demonstrate successful integration of oral health into broader healthcare systems, serving as models for preventive and therapeutic care.

- Canada's approach highlights the importance of targeted initiatives for underserved populations, while Saudi Arabia's focus on sugar reduction and prenatal education addresses the root causes of oral health issues.

6.3 Brazil's *Smiling Brazil* program

- *Overview:*

  Launched in 2004, Brazil's Smiling Brazil program (Programa Brasil Sorridente) integrates oral health into the country's Unified Health System (SUS) [20].

  The program aims to provide universal access to preventive and curative dental care, particularly for underserved communities.

- *Achievements:*

  Expanded access to oral health services through family health teams and specialized dental centers.

  Reduced tooth loss and improved oral health literacy across diverse demographics.

- *Innovative approaches:*

  Emphasis on school-based prevention programs, including fluoride varnish application and oral health education.

  Integration of oral health services into primary healthcare settings for holistic patient care.

- *Challenges:*

- Despite significant progress, disparities persist in rural and remote areas due to resource constraints [20].

6.4 Qatar's Asnani school oral health program

The Asnani School Oral Health Program represents a significant evolution in Qatar's approach to school-based oral health initiatives. Introduced in 2016, Asnani replaced the Old Dental School Program, addressing its limitations and introducing a comprehensive framework for oral health promotion and prevention among children [23].

6.4.1 The old dental school program

- *Scope:*

  Established over 30 years ago, the Old Dental School Program primarily targeted children in grades 1 and 4 in primary schools and all kindergarten students.

  Services included routine dental examinations, fluoride varnishes, and referrals for further treatment.

  Dental services were provided by three health centers, staffed by nine dentists and ten dental assistants, operating in two shifts.

- *Limitations:*

  Grade selection:

- Although cSchools are grades 1–6, the old dental school program selected grades 1 and 4. Could not cover all kindergarten schools.

6.4.2 The Asnani program: A new initiative

The introduction of the Asnani School Oral Health Program marked a transformative shift toward a more preventive, community-driven approach in Qatar. Asnani aims to expand access, enhance the quality of care, and foster lifelong oral health habits through a comprehensive and culturally integrated framework.

6.4.3 Key features of Asnani

1. *Preventive services:*

   - Routine dental screenings, fluoride varnishes, fissure sealants, and personalized oral health advice tailored to individual needs.

   - Electronic parental consent introduced to ensure efficiency, transparency, and ethical compliance.

2. *Parental engagement:*

   - Active involvement of families in promoting oral health through consent and participation in oral health education sessions.

3. *Education and behavioral change:*

    - Focused on instilling proper brushing techniques, dietary awareness, and the importance of regular dental visits through engaging materials and interactive activities.

4. *Cultural integration:*

    - Incorporates traditional practices such as the use of the miswak and blending cultural heritage with modern preventive dentistry.

5. *Collaborative approach:*

    - Partnerships with schools, teachers, and healthcare providers to ensure the efficient delivery of services and seamless integration of oral health promotion into school routines.

6.4.4 Program description

- *Target population:*
- *Core services:*

    Preventive care through fluoride varnishes, fissure sealants, and regular dental checkups.

    Oral health promotion through workshops and tailored educational resources.

- *School coverage:*

    2022–2023: Reached 161 schools, covering 97% of kindergartens and 84% of primary schools.

    2023–2024: Coverage included 140 schools, with 85% of kindergartens and 77% of primary schools.

- *Student participation:*

    2022–2023: Screened 32,108 students, with 24,646 requiring treatments.

    2023–2024: Screened 30,214 students, with a caries prevalence of 70% in kindergartens and 34% in primary schools.

- *Fluoride varnish applications:*

    Increased significantly from 4764 applications in 2022–2023 to 17,496 in 2023–2024.

6.4.5 Outcomes

- Awareness:

Significant improvements in oral health awareness among children, families, and school communities.

- Caries reduction:

  Among 12-year-old students, caries levels have reached the WHO optimal threshold for high caries reduction, demonstrating the program's success in aligning with the global health standards.

- Community impact:

  A measurable decrease in the prevalence of dental caries among school-aged children, evidenced by monitoring and evaluation reports.

- Sustainability:

  Electronic systems for tracking and reporting enhanced operational efficiency and data accuracy.

6.4.6 Impact

By addressing the gaps in the Old Dental School Program, the Asnani initiative has transformed school-based oral health care in Qatar. Its emphasis on prevention, education, and community involvement has established a sustainable framework for improving oral health outcomes for future generations. This framework not only enhances access to care but also ensures that Qatar remains aligned with international benchmarks in oral health promotion and prevention (**Figures 1** and **2**).

6.5 Senan' nursery oral health promotion

The *Senan* Nursery Oral Health Promotion Programme has recently been launched by the Primary Health Care Corporation (PHCC) in collaboration with the Ministry

Figure 1.
Asnani team at primary school.

Figure 2.
Kindergarten students assigned to health centers under the Asnani Program.

of Education and Higher Education. It was developed in response to alarming findings that 61% of kindergarten children in Qatar were affected by tooth decay during the 2022–2023 academic year. This initiative reflects PHCC's commitment to early intervention and prevention by promoting oral health practices in early childhood settings [22].

6.5.1 Objectives

- To improve oral health among children under 4 years of age in both public and private nurseries.
- To reduce the prevalence of early childhood caries through education and preventive measures.
- To strengthen the oral health knowledge, attitudes, and behaviors of parents, caregivers, and nursery staff.
- To promote healthy dietary habits and eliminate harmful oral behaviors among young children [23].

6.5.2 Target groups

- Nursery children under the age of four
- Nursery teachers and staff
- Parents and caregivers of enrolled children
- Nursery nurses and support staff

6.5.3 Program components

- Oral health education for children: Interactive sessions using cartoons, flip cards, toothbrushing songs, art activities, and food sorting games.
- Toothbrushing calendar: One-month activity with stickers to encourage consistent brushing at home.
- Oral health education for parents: Booklets, awareness sessions, caries identification activity, and feedback collection.
- Oral health education for teachers: Pre- and post-program assessments and training to support classroom-based oral health promotion.
- Screening and fluoride varnish application: Delivered by dental hygienists during scheduled open house days [5].
- Open day and competitions: Art exhibitions, smile photography contests, and parent-child activities emphasizing the importance of oral health.

6.5.4 Implementation strategy

- Coordination between PHCC, Ministry of Education, and nurseries to ensure seamless rollout.
- Delivery of oral health education using structured materials and engaging tools tailored for preschoolers [12].
- Training for nursery staff and regular communication with parents to support ongoing oral health practices at home and in the nursery.
- Integration of oral screening for early detection of dental issues among nursery children during the program.
- Application of fluoride varnish by qualified dental hygienists as a preventive measure during scheduled activities and open day events.
- Collection of baseline and post-program data to evaluate changes in knowledge, attitudes, behaviors, and oral health status.
- Organization of annual open house events at health centers to engage families, display children's activities, and reinforce key oral health messages.

6.5.5 Expected outcomes

- Increased oral health literacy among parents, teachers, and children [24].
- Reduction in harmful oral behaviors and improvement in daily oral hygiene practices.
- Increased percentage of children receiving fluoride varnish applications.

- Greater satisfaction among parents and teachers regarding the program's relevance and impact [9].
- Enhanced nursery participation in preventive oral health activities.
- Development of a sustainable model for oral health promotion in early childhood education settings.

It is important to note that the Senan Nursery Oral Health Promotion Programme has only recently been launched and is currently in its early implementation phase [22]. As such, the full cycle of activities, including comprehensive evaluations and outcome measurements, is yet to be completed. Future reporting will reflect on key performance indicators and the program's overall impact on oral health behaviors and outcomes among nursery-aged children, their families, and caregivers. The early engagement and structured approach, however, position Senan as a promising foundation for sustainable oral health promotion in early childhood settings across Qatar.

6.6 Oral health ambassadors program

The oral health ambassadors program is an integral component of the Asnani School Oral Health Program, designed to leverage parental engagement to promote oral health within school communities. By incorporating this initiative into the broader Asnani framework, the program aims to strengthen community-driven approaches to oral health education and advocacy. It uses parental meetings as a platform to educate and empower parents, teachers, and school staff to advocate for improved oral hygiene practices among children and the wider community.

6.6.1 Objectives

- Enhance awareness of oral health among parents, students, and school staff.
- Promote good oral hygiene practices at home and school.
- Foster a community-wide commitment to oral health.

6.6.2 Target group

Teachers, school administrators, and staff will later target parents through parental meetings and students within schools (**Figure 3**).

6.6.3 Program components

1. *Training oral health ambassadors:*
    - Conduct workshops for teachers and school administrative staff to prepare them as oral health ambassadors.
    - Provide ambassadors with educational resources, such as PowerPoint presentations, brochures, posters, and tools for effective communication.

Figure 3.
Oral health ambassador for teachers and school's administrators.

2. *Educational activities:*

    - Deliver interactive presentations during parental meetings using multimedia tools.

    - Facilitate Q and A sessions to address parental concerns about oral health.

3. *Distribution of oral health kits:*

    - Provide take-home kits containing toothbrushes, toothpaste, floss, and educational brochures.

4. *Collaboration with schools:*

    - Integrate oral health into the school curriculum.

    - Advocate for school policies promoting oral health (e.g., healthy snacks, regular dental checkups).

5. *Community engagement:*

    - Organize health fairs and events focused on oral health.

    - Use social media campaigns to spread awareness and share program updates.

6.6.4 Implementation strategy

1. *Initial assessment*: Conduct surveys and interviews to gauge current oral health practices and awareness.

2. *Pilot phase*: Launch the program in a small group of schools to test and refine the approaches.

3. *Expansion*: Scale up to include more schools, incorporating feedback from the pilot phases.

4. *Continuous evaluation*: Monitor the program's impact using regular feedback, oral health data, and practice changes.

6.6.5 Expected outcomes

- *Increased awareness*: Parents will better understand oral health practices, fostering healthier routines at home.

- *Improved oral hygiene*: Students will adopt better oral hygiene habits, reducing dental issues.

- *Community engagement*: A collaborative network of parents, teachers, and administrators will advocate for improved oral health.

6.7 Qatar's "Ejlal" home oral health care services program

Qatar's *"Ejlal" Home Oral Health Care Services Program (Ejlal is an Arabic word that means respect and esteem)*, launched in June 2023 as a three-phase pilot [25], is among the pioneering initiatives in the GCC region specifically designed to address the oral health needs of the elderly. This program provides in-home oral assessments, education, prevention, and prioritized dental treatment referrals for seniors [26]. While other GCC countries have implemented general oral health campaigns and services, dedicated programs focusing exclusively on elderly oral health are less common. For instance, Saudi Arabia participates in the GCC Oral Health Unified Week, promoting dental health across all age groups, but lacks a specific programs for the elderly [25, 27].

6.7.1 Qatar renames "Elderly"

On November 11, 2024, Circular No. 20 of 2024, issued by the Minister of State for Cabinet Affairs, instructed all ministries, government agencies, and public institutions to adopt the term "*Kibar Al-Qadr*" *(Persons of Great Esteem)* in place of "*Kibar Al -Sinn*" *(Elderly)* in all correspondences, websites, and official statements. This change underscores the importance of using respectful and dignified terminologies, further emphasizing the cultural and societal value of this demographics.

The *Ejlal* program represents a significant advancement in addressing the unique oral health requirements of the aging population within the region, aligning healthcare delivery with Qatar's commitment to respect and dignity for its elderly citizens [27].

6.7.2 Program description

- *Target population:*

- *Services provided:*

  Mobile dental units deliver oral health care directly to patients' homes.

Comprehensive assessments include oral cancer screenings, education for seniors, and guidance for caregivers.

Preventive services focus on reducing oral disease risk and improving quality of life.

- *Innovations:*

Emphasis on personalized care plans tailored to individual needs.

Caregiver education to ensure consistent oral hygiene practices for dependent elders.

Integration with geriatric healthcare services to address systemic and oral health needs simultaneously.

6.7.3 Program phases and successes

6.7.3.1 Pilot phase overview

The Ejlal program's three-phase pilot was conducted between June 2023 and January 2024, with each phase focusing on different aspects of implementation and scalability. As part of the process, verbal consents were obtained from participants prior to home visits, with totals recorded and compared across all three phases, as detailed in **Table 1**.

1. Phase 1 (June 4–22, 2023):
    - Covered 17 health centers.
    - Contacted 737 elderly patients, with 445 providing positive verbal consent (60% acceptance rate).
2. Phase 2 (July 9–August 17, 2023):
    - Conducted 350 home visits, identifying high rates of gingivitis (21%), periodontitis (27%), and untreated dental caries (51%) [13].
    - Focused on providing education to elderly patients and caregivers.
3. Phase 3 (December 6, 2023–January 7, 2024):
    - Expanded to 23 health centers, completing 195 home visits.

	Total	Phase 1	Phase 2	Phase 3
Verbal consents obtained	1098	416	312	370
Home visits conducted	800	350	255	195

Table 1.
Verbal consents obtained during Ejlal program's three-phase pilot.

- Addressed patients missed in earlier phases, with 34% referred for further dental treatment.

6.7.3.2 Educational component

- 97–100% of elderly patients and caregivers received oral health education and dietary counseling.
- Sessions emphasized daily oral hygiene, proper denture care, and reducing oral disease risks through lifestyle changes.

6.7.3.3 Key outcomes

- *Screening and referrals:*

  A total of 800 home visits were completed across all phases, with 261 patients referred for dental treatment.

- *Improved oral health status:*

  Prevalence of oral conditions was documented, enabling targeted interventions:

  Gingivitis: 21%.

  Periodontitis: 27%.

  Untreated dental caries: 51%.

  Edentulousness: 21%, with 36% requiring denture replacements.

- *Awareness and education:*

  Educational efforts resulted in better daily oral hygiene practices among participants, with 78–88% of elderly patients practicing regular oral hygiene.

- *Public health impact:*

  The program addressed a critical gap in elderly oral health care in the GCC region, promoting integration into national health strategies and achieving high participant satisfaction (87–96% rated services as excellent or good) (**Figures 4** and **5**).

6.8 Lessons learned

- *Global collaboration:*

  Programs like Smiling Brazil demonstrate the importance of integrating oral health into national health systems [20].

  Qatar's innovative approaches emphasize the potential of culturally tailored programs to meet the local needs [22].

Figure 4.
Elderly signed Ejlal team's consent form.

Figure 5.
Ejlal team examine elderly at home.

- *Scalability and sustainability:*

  Success requires sustained funding, community engagement, and continuous evaluation to adapt to evolving public health needs.

- *Future directions:*

  Cross-border knowledge sharing can enhance the effectiveness of oral health programs, particularly in regions with similar challenges.

6.8.1 Future plans

1. Transition Ejlal from a pilot initiative to a fully integrated national program.

2. Enhance operational efficiency through better transportation logistics and up-dated patient databases.

3. Expand program reach to include additional health centers and introduce routine follow-ups for improved care continuity.

6.9 Key differences in elderly oral health programs

6.9.1 Australia

The Australian government identifies specific groups of older adults who are highly disadvantaged in terms of oral health and access to dental care. These groups include socially disadvantaged or low-income individuals, Indigenous Australians, rural and remote dwellers, and older adults with special needs. To address these challenges, Australia has initiated or reformed healthcare systems and developed innovative approaches to deliver oral health services for older adults, including home-based care.

6.9.2 United States

Home-based dental care services have been developed to cater to homebound elderly individuals. For example, House Call Dentists provide dental care to those who are unable to visit traditional dental offices. However, the fragmented healthcare system often leaves economically disadvantaged groups underserved, with access largely dependent on insurance coverage or out-of-pocket payment.

6.9.3 Sweden

Sweden has a robust system for elder care, including oral health services. The government provides subsidies for dental care, ensuring affordability. Specialized programs exist to deliver oral health services to the elderly in their homes or residential facilities, particularly for those with mobility or health challenges. This comprehensive approach integrates oral care within the broader healthcare system for seniors.

6.9.4 Canada

Canada has several home-based oral health care initiatives, often delivered through local public health units or private services. These programs focus on providing oral health care to seniors living at home or in long-term care facilities. Mobile dental clinics in some provinces bring preventive and restorative care directly to the elderly, addressing accessibility challenges for homebound individuals.

6.9.5 Denmark

Denmark offers home-based oral health services as part of its comprehensive elder care system. Public dental care services are extended to seniors who face mobility issues or live in nursing homes. Dental hygienists or dentists visit patients at home to provide preventive and therapeutic care, ensuring equitable access to services. The integration of oral health into elder care services is a hallmark of Denmark's approach.

6.9.6 Switzerland

The Swiss government has implemented policies to promote sugar-free products with the "Toothfriendly" seal of quality, aiming to reduce tooth decay among the population.

While specific home-based programs are not detailed, such national initiatives contribute to improved oral health outcomes for all age groups, including the elderly.

6.9.7 Thailand

With supportive policies like the National Health Development Strategic Plan for the Elderly (2013–2023) and the Universal Health Coverage (UHC), Thailand has developed the National Oral Health Plan for the Elders 2016–2022. This plan drives a wide range of programs and services, including home-based oral health care for older adults. The focus is on preventive care, integrating oral health into broader health strategies for the elderly.

6.9.8 Qatar

Recognizing the importance of good oral health as an essential part of healthcare for the elderly, Qatar has proposed models for domiciliary oral healthcare services [26, 27]. These models aim to align the existing health system with the needs and preferences of elderly individuals, providing oral health services directly in their homes. The integration of preventive and curative care into home-based services reflects Qatar's focus on comprehensive healthcare delivery.

6.10 Streamlined overview

- Countries such as Denmark, Sweden, and Australia excel in integrating oral health into national elder care systems.

- Thailand and Qatar focus on preventive strategies, highlighting emerging models in developing systems.

- Canada and the United States offer regionally varied services with innovative solutions like mobile clinics and home visits, but accessibility may depend on private funding.

7. Community engagement and public health strategies

Community engagement is a cornerstone of effective oral health promotion. Public health strategies that involve local populations, caregivers, and stakeholders can address oral health disparities and foster sustainable improvements in health outcomes.

7.1 Importance of community engagement

- *Empowering individuals:*

  Community engagement empowers individuals to take ownership of their oral health, leading to better adherence to preventive practices.

  Educating families about oral health fosters long-term behavioral changes, reducing the burden of preventable diseases.

- *Addressing disparities:*

  Community programs focus on underserved populations, ensuring equitable access to oral health services and education.

- *Building trust:*

  Engaging local communities builds trust in health systems, facilitating the successful implementation of programs.

7.2 Community-based approaches to oral health

7.2.1 Partnerships with media

- Collaborations with media outlets to disseminate culturally relevant oral health messages through television, newspapers (in both Arabic and English), radio, and social media platforms, reaching diverse populations [22–24].

- These efforts amplify oral health awareness, encourage preventive care practices, and promote the adoption of healthier habits within the community.

7.2.2 Caregiver education

- Educating caregivers about maintaining oral health for children, individuals with special needs, and elderly individuals fosters a supportive environment for preventive practices.

- Caregiver education emphasizes the importance of daily oral hygiene, the use of fluoride toothpaste, and adopting proper dietary habits to reduce the risk of caries and gum disease.

- For elderly individuals, caregiver education addresses specific challenges, including:

  Assisting with oral hygiene for dependent adults.

  Managing dry mouth and its associated effects.

  Ensuring proper care and maintenance of dentures and other prosthetic devices.

7.2.3 Community organizations

- Collaborations with local societies help tailor oral health initiatives to address specific community needs, ensuring accessibility for everyone, including underserved populations.

- Mobile dental units partnered with community centers increase access to preventive care and education in various areas, particularly for those with the limited mobility or access to dental clinics.

7.3 Culturally tailored programs

- *Culturally responsive approaches:*

  Programs designed to align with the cultural values and preferences of the community foster better acceptance and engagement.

  Tailoring oral health education to reflect local traditions and lifestyles ensures relevance and practicality.

- *Multilingual outreach:*

  Providing educational materials in multiple languages enhances inclusivity and accessibility, allowing diverse populations to benefit from the program.

  Ensuring clear and culturally sensitive communication bridges gaps in understanding and encourages widespread participation.

7.4 Community-based research

- *Identifying local needs:*

  Research involving community members helps identify specific oral health challenges and tailor interventions to address them.

- *Participatory approaches:*

  Collaborative research methodologies encourage community participation, ensuring that interventions are relevant and culturally appropriate.

- *Data-driven decisions:*

  Collecting and analyzing data on community oral health status enables policy-makers to allocate resources effectively and prioritize high-impact initiatives.

7.5 Partnerships and stakeholder involvement

- *Interdisciplinary collaboration:*

  Partnerships between dental professionals, primary healthcare providers, and public health experts ensure holistic care.

  Collaboration with government agencies and non-governmental organizations (NGOs) supports resource mobilization and program sustainability.

- *Corporate Social Responsibility (CSR):*

- Involving private-sector stakeholders through CSR initiatives can fund community programs and increase their reach.

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8. What makes such programs successful

The success of oral health programs lies in meticulous planning, ethical considerations, and adaptive strategies that cater to the needs of diverse populations. Key elements such as informed consent, clear guidelines, targeted surveys, and research play crucial roles in ensuring these programs achieve their objectives and maintain sustainability.

8.1 Informed consent

- *Children (Asnani School Oral Health Program):*

  Parents are provided with detailed consent forms explaining procedures such as dental examinations, fluoride varnishes, and oral health education.

  These forms outline confidentiality measures, allowing parents to ask questions before signing and giving them the option to opt out of specific services if desired.

  Forms are collected through schools and securely stored to comply with privacy regulations.

- *Elderly (Ejlal Home Oral Health Services):*
- Elderly participants or their caregivers are asked to sign consent forms before assessments and treatments, such as denture maintenance and oral cancer screenings.
- For participants unable to consent due to physical or cognitive limitations, authorized caregivers are permitted to sign on their behalf.
- Consent procedures ensure ethical compliance and transparency, fostering trust between participants and healthcare providers.

8.2 Guidelines for service delivery

- *Standardized protocols:*

  Clear and concise guidelines ensure uniform delivery of oral health services across different settings, such as schools, homes, and community centers.

  These protocols outline procedures for dental screenings, fluoride applications, and referral systems for advanced care.

- *Culturally tailored practices:*

  Programs integrate culturally relevant practices, such as using the miswak alongside modern techniques, to enhance community acceptance.

- *Training for staff:*

  Teams involved in service delivery receive comprehensive training on technical skills, communication strategies, and cultural sensitivity to maintain the high standards of care.

8.3 Targeted surveys and feedback mechanisms

- *Customized surveys for each group:*

  Children: Surveys assess oral hygiene habits, knowledge about caries prevention, and the impact of school-based programs like Asnani.

  Elderly: Surveys focus on challenges such as dry mouth, denture usage, and accessibility of services provided by Ejlal.

  Caregivers: Gather insights on the support required for maintaining oral health in children and elderly dependents.

- *Real-time feedback:*

  Participants and caregivers can provide feedback through digital platforms or in-person interviews, enabling responsive adjustments to services.

8.4 Research and data utilization

- *Baseline assessments:*

  Collecting data on oral health status before implementing programs establishes benchmarks for measuring progress.

- *Impact studies:*

  Research evaluates the effectiveness of interventions, such as the reduction in caries prevalence among children participating in the Asnani program or improvements in oral health-related quality of life among elderly participants in Ejlal.

- *Longitudinal studies:*

  Tracking participants over time provides valuable insights into the sustained impact of oral health programs.

- *Collaboration with academic institutions:*

  Partnering with universities enhances the credibility of findings and promotes evidence-based improvements to program design.

9. Summary

This chapter explores the critical integration of oral health into systemic healthcare frameworks, emphasizing its essential role in enhancing individual and population health outcomes. Drawing on global innovations and localized successes, it illustrates how comprehensive oral health strategies can be aligned with broader public health objectives.

Countries such as Australia, Sweden, and Denmark exemplify effective integration of oral health into elder care systems, while Qatar's pioneering initiatives, such as the Asnani and Ejlal programs, demonstrate how culturally rooted practices can be combined with modern preventive approaches to achieve measurable improvements. These models underscore the importance of community involvement, workforce training, and the incorporation of traditional values in promoting sustainable oral healthcare.

Moreover, the chapter highlights how technological advancements ranging from laser therapies and salivary diagnostics to teledentistry are reshaping the landscape of preventive and therapeutic dental care. These innovations not only enhance access and precision but also hold promise for addressing oral health disparities in underserved populations.

Adopting a life-course perspective, the chapter calls for oral health promotion to begin early and extend throughout aging, supported by interdisciplinary collaboration and culturally sensitive strategies. By presenting evidence-based practices and policy recommendations, the chapter serves as a call to action for healthcare providers, educators, and decision-makers to prioritize oral health within systemic health frameworks and foster equity, resilience, and well-being in communities worldwide.

Key highlights include:

- *Global innovations*: Case studies from countries such as Australia, Sweden, and Denmark showcase effective integration of oral health into elder care systems, emphasizing home-based services and preventive approaches.

- *Qatar's leadership*: Programs like *Asnani* and *Ejlal* illustrate Qatar's pioneering role in combining traditional practices with modern preventive dentistry, reflecting culturally sensitive and innovative oral healthcare solutions.

- *Technological advancements*: Emerging technologies, including laser therapies, teledentistry, and salivary diagnostics, underscore the transformative potential of innovation in enhancing access, precision, and health outcomes.

The chapter emphasizes a life-course perspective, advocating for oral health promotion from early prevention through advanced geriatric care. It calls for interdisciplinary collaboration, workforce development, and culturally tailored interventions to address barriers to care, particularly in underserved and aging populations.

By combining evidence-based strategies and practical insights, this chapter serves as a call to action for policymakers, healthcare providers, and educators. It aligns oral health promotion with global health priorities, demonstrating the potential of innovation and community-driven approaches to achieve equity and resilience in healthcare systems.

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Chapter 3

Foundations of Oral Health

Manal A. Ablal

Abstract

This chapter provides a broad overview of oral health, focusing on the impact of common oral conditions across the human lifespan. It explores the fundamental anatomy and function of the oral cavity, examining key aspects such as tooth development, eruption, and the factors influencing these processes. The chapter emphasizes prevalent oral health issues such as dental caries, gingivitis, periodontal disease, and oral infections, discussing both their clinical manifestations and systemic implications. Consideration is given to age-specific oral health needs, from early childhood through older age, emphasizing the importance of appropriate preventive care and treatment strategies. The chapter further explores the relationship between oral health and systemic health, with a focus on how oral conditions can affect and be affected by broader medical issues. While not an exhaustive review of all possible oral diseases, this chapter provides the foundational knowledge necessary for understanding essential oral health issues, their prevention, and their clinical management across different life stages.

Keywords: tooth development, oral health conditions, oral infections, oral cancer, professional interventions, age-specific care, preventive strategies

1. Introduction

Oral health is an essential component of overall well-being, influencing nutrition, speech, and quality of life. Poor oral health can lead to common oral diseases such as dental caries, gingivitis, and periodontal disease, which, far from being isolated to the mouth, can also impact systemic health. These conditions may influence and be influenced by overall systemic health, highlighting the critical connection between oral and general health.

This chapter begins by exploring dental embryology, including the formation of the tooth germ and the differentiation of ameloblasts and odontoblasts. It then explores the development of other dental structures—cementum, periodontal ligament, and alveolar bone—highlighting their clinical significance and relevance to congenital and developmental anomalies.

A range of oral conditions is investigated, including congenital anomalies like anodontia, ectodermal dysplasia, and cleft lip and palate, as well as developmental disorders such as amelogenesis imperfecta, dentinogenesis imperfecta, taurodontism, and dental agenesis. Each is described in terms of its etiology, clinical presentation, and management.

The chapter also highlights preventive measures—including oral hygiene practices, fluoride therapy, dietary modification, and sealants—as well as diagnostic strategies. These include routine clinical evaluation and selected mention of technological advances, such as autofluorescence imaging and histopathological analysis, that aid in the early detection of oral pathologies.

This chapter aims to provide readers with a focused understanding of the fundamental oral health issues affecting people across different life stages, emphasizing key anatomical, pathological, and clinical aspects. In order to retain the primary focus on essential concepts, images have been excluded from the chapter; however, the comprehensive reference section can be used for further exploration of these topics.

2. Dental embryology

Dental embryology is a critical aspect of understanding the formation and development of the teeth. The process begins early in fetal life, at around 6 weeks' gestation, through a series of complex interactions between the ectoderm and mesoderm germ layers.

2.1 Formation of the tooth germ

The tooth germ, also known as the enamel organ, is the embryonic structure from which the tooth will develop. The formation starts with the thickening of the oral epithelium, which is a squamous stratified epithelium that covers the entire surface of the oral mucosa. It is a highly organized, avascular, and semipermeable tissue whose thickness and degree of keratinization vary according to the location in the oral cavity and the area's functional and mechanical requirements [1]. This thickening forms the dental lamina, which gives rise to a series of epithelial buds that invaginate into the underlying mesenchyme. The interaction between the ectoderm-derived epithelial cells and the mesoderm-derived mesenchymal cells marks the initiation of the complex process of tooth formation [2].

2.2 Differentiation of ameloblasts and odontoblasts

As the tooth germ continues to grow, the cells within it undergo differentiation and specialization, forming distinct structures of the developing tooth. Ectoderm-derived cells give rise to ameloblasts, responsible for synthesizing enamel, the hardest substance in the human body. These cells undergo significant morphological changes as they differentiate, eventually becoming columnar and secreting enamel proteins to form the enamel layer [2].

Meanwhile, mesoderm-derived mesenchymal cells give rise to odontoblasts, which differentiate adjacent to the inner enamel epithelium. Odontoblasts are responsible for synthesizing and depositing dentin, the mineralized tissue that provides support to the enamel and forms the majority of the tooth structure. Odontoblasts produce a specialized extracellular matrix that progressively mineralizes, ultimately forming the predentin, which mineralizes into dentin layers [2].

2.3 Formation of other dental tissues

Beyond the development of ameloblasts and odontoblasts, other essential dental tissues form as mesenchymal cells differentiate during odontogenesis.

2.3.1 Cementum

Cementoblasts, specialized cells derived from mesenchymal cells around the tooth's root, are responsible for the production of cementum, a mineralized tissue that covers the tooth root. Cementum serves as an attachment site for periodontal ligament fibers and ensures the stability of the tooth within the alveolar bone socket. Furthermore, cementum provides structural support to the overlying dentin and enamel structures [3].

2.3.2 Periodontal ligament

The periodontal ligament fibers primarily originate from fibroblasts within the dental follicle, which surrounds the developing tooth germ. These fibroblasts synthesize extracellular matrix components, particularly collagen fibers, forming a network that supports the tooth in its alveolar bone socket. The periodontal ligament not only enables the tooth to withstand masticatory forces but also allows for limited movement, contributing to proprioceptive functions necessary for proper occlusion [4].

2.3.3 Alveolar bone

The alveolar bone, or alveolar process, forms the bony socket within the maxilla and mandible that houses the tooth roots, providing a stable base for the teeth. Continuous remodeling of this bone occurs throughout life to adapt to changes in masticatory forces and periodontal health. During odontogenesis, mesenchymal cells within the dental follicle differentiate into osteoblasts, which synthesize the alveolar bone matrix [4].

2.3.4 Clinical significance and implications

Understanding the development of essential dental tissues is crucial for dental professionals. It aids in recognizing and managing various pathologies and anomalies arising during odontogenesis. This knowledge lays the groundwork for innovative therapeutic approaches in regenerative dentistry, such as regenerating damaged or lost dental tissues and treating both congenital and developmental dental disorders. By comprehending the intricate processes involved in the formation of cementum, periodontal ligaments, and alveolar bone, clinicians can develop more effective diagnosis, treatment, and prevention strategies to maintain optimal oral health.

Odontogenesis, the process of tooth development, involves complex interactions between epithelial and mesenchymal cells. Any disruptions in these interactions can result in various congenital and developmental anomalies that may significantly impact both oral health and function. The following sections will discuss some of these dental disorders, providing insights into their underlying mechanisms, clinical manifestations, and potential treatment approaches.

2.3.4.1 Congenital disorders

2.3.4.1.1 Anodontia

This condition is characterized by the complete absence of teeth due to the failure of tooth development. It can occur in isolation or as part of certain genetic syndromes, such as ectodermal dysplasia. Individuals affected by anodontia typically require prosthetic rehabilitation, which may involve removable dentures, implant-supported prostheses, or orthodontic interventions to enhance masticatory function and aesthetics [5].

2.3.4.1.2 Ectodermal dysplasia

A group of hereditary disorders that impact the development of ectodermal tissues, including teeth, hair, nails, and sweat glands. Dental manifestations may include anodontia, hypodontia, or conical-shaped teeth. Multidisciplinary care, including dental prosthetics, plays a crucial role in managing these patients [6].

2.3.4.1.3 Cleft lip and palate

These congenital conditions are characterized by incomplete fusion of the lip, palate, or both during early fetal development. These conditions often lead to dental anomalies, such as malocclusion, along with challenges in speech and feeding. Treatment typically involves surgical repair followed by orthodontic management and restorative interventions to optimize aesthetics, function, and overall oral health [7].

2.3.4.1.4 Dens invaginatus

Also known as "dens in dente," is a dental anomaly resulting from an invagination in the surface of a tooth. It most commonly affects the maxillary lateral incisors but has also been observed in the maxillary central incisors and mandibular incisors. This condition increases susceptibility to dental caries, pulpitis, and periodontal inflammation. Treatment varies depending on the severity of the invagination, with options ranging from preventive measures to more invasive procedures like root canal therapy [8].

2.3.4.2 Developmental disorders

2.3.4.2.1 Supernumerary teeth (hyperdontia)

Additional teeth may develop in excess of the typical number of teeth in the dental arch, potentially causing issues like malocclusion, crowding, or impaction of adjacent teeth. Early detection through radiographic evaluation and surgical intervention can prevent complications and maintain the health of surrounding tissues [5].

2.3.4.2.2 Amelogenesis imperfecta (AI)

AI is a group of inherited disorders affecting the formation and mineralization of dental enamel. These structural defects can result in enamel that is thin, soft, and discolored, causing rapid wear, increased sensitivity, and susceptibility to caries [9]. Treatment focuses on preserving existing tooth structure, reducing sensitivity, improving aesthetics, and preventing further damage. Early diagnosis, preventive measures, and appropriate dental care are essential for managing complications and ensuring optimal oral health and quality of life for patients. Some common treatment options include:

- Composite bonding: Application of tooth-colored resin to cover and protect the affected enamel.
- Veneers: Thin porcelain or composite shells bonded to the front surfaces of teeth to enhance appearance and protect them from wear.

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- Crowns: Full-coverage restorations that encase the entire visible portion of the tooth for added strength and durability.

- Remineralizing agents: Topical applications of fluoride or other remineralizing agents to strengthen the enamel and reduce sensitivity.

2.3.4.2.3 Dentinogenesis imperfecta (DI)

DI is a genetic condition affecting the formation of dentin, the layer beneath the enamel. This disorder results in compromised dentin that is often discolored and structurally weak, making teeth more susceptible to fractures and wear. Clinical management focuses on maintaining tooth function, improving aesthetics, and preventing further complications [9]. As with amelogenesis imperfecta, early diagnosis, preventive measures, and appropriate dental care are crucial for effective management and optimal patient outcomes. Treatment strategies may include:

- Crowns: Full-coverage restorations that protect the weakened tooth structure from further damage.

- Overlays or inlays: Restorations made from materials such as ceramic or composite, covering or replacing the damaged dentin to reinforce the tooth.

- Endodontic treatment: In cases where the dental pulp is compromised, root canal therapy may be necessary to address pain, inflammation, or infection.

- Dental implants: For severely affected teeth, extraction and replacement with dental implants may be considered to restore function and aesthetics.

For both Amelogenesis Imperfecta (AI) and Dentinogenesis Imperfecta (DI), early diagnosis, preventive measures, and appropriate dental care are essential for managing complications and ensuring optimal oral health and quality of life for patients.

2.3.4.2.4 Dental agenesis

Also known as tooth agenesis or failure of tooth development, is a condition characterized by the absence of one or more permanent teeth. This anomaly can occur in both the primary and permanent dentitions. Commonly affected teeth include third molars, maxillary lateral incisors, and mandibular second premolars. The severity of this condition can range from the absence of a single tooth (hypodontia) to multiple missing teeth (oligodontia) or complete absence of teeth (anodontia). Management strategies depend on the location and number of missing teeth, as well as patient factors such as age and growth status [5]:

- Orthodontic treatment: Space management and orthodontic appliances can help close gaps, align remaining teeth, and create space for prosthetic replacements.

- Dental implants: Implant-supported restorations can provide a long-term solution for replacing missing teeth, particularly in adult patients with fully developed jawbones.

- Prosthetic rehabilitation: Fixed or removable prostheses, such as bridges, dentures, or resin-bonded bridges, can help restore function and aesthetics.

- Regular dental monitoring and maintenance: Ensuring good oral hygiene and addressing potential complications such as malocclusion, periodontal issues, or dental caries in adjacent teeth.

2.3.4.2.5 Taurodontism

Is a dental anomaly characterized by disorganized calcified tissues in permanent dentition. Affected teeth exhibit enlarged pulp chambers, shortened roots, and a reduced furcation area near the cervical region of multi-rooted teeth [10]. It can occur either as an isolated trait or in association with various syndromes such as Down syndrome, ectodermal dysplasia, and amelogenesis imperfecta [11]. The prevalence of taurodontism varies greatly, ranging from 0.5 to 46%, depending on the population studied. Management of this condition generally involves:

- Early diagnosis: Routine radiographic examinations help detect affected tooth/teeth, especially in high-risk patients or those with suspected associated syndromes.

- Regular monitoring: Close follow-up and dental examinations to identify potential complications such as caries, periodontal disease, or pulpitis.

- Endodontic considerations: Due to the enlarged pulp chambers and potentially complex root canal anatomy, endodontic treatment may be more challenging and require special attention.

2.3.4.2.6 Dilaceration

Is a dental anomaly that results from trauma or insufficient developmental space, often affecting third molars. In this condition, there is a deviation or distortion in the linear relationship between the tooth crown and root, causing root angulation or deformation. The main challenge with dilacerated teeth lies in their extraction due to the increased risk of root fractures [12]. Treatment considerations for dilaceration may include:

- Surgical extraction: Removal of dilacerated teeth may require surgical intervention to minimize trauma and prevent root fractures.

- Radiographic examination: Accurate imaging is essential for proper treatment planning and assessing the degree of root angulation.

- Monitoring adjacent teeth: Regular dental checkups to ensure the health and stability of neighboring teeth.

- Orthodontic treatment: In some cases, orthodontic therapy may be used to create sufficient space for proper tooth eruption and alignment.

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2.3.4.2.7 Dense Evaginatus (DE)

This is an odontogenic developmental anomaly characterized by the presence of an extra cusp or tubercle on the occlusal surface of affected teeth [13]. The additional cusp is typically found on the lingual or buccal surface of molars and premolars, although it can occur on other teeth as well. The prevalence of DE ranges from 0.5 to 4.3% in different populations, with higher frequencies reported in individuals of Asian descent [13].

The etiology of this condition is not fully understood, but it is generally considered to result from an evagination of the inner dental epithelium and subsequent invagination of the surrounding mesenchyme during the morpho-differentiation stage of tooth development. This process leads to the formation of an accessory cusp or tubercle [13].

The additional cusp in DE contains a central pulp horn, dentin core, and enamel covering. The dentin core may or may not extend into the pulp, with variations in its size and proximity to the pulp tissue. When the pulp is unaffected, the extra cusp can be managed with preventive methods such as selective grinding or sealing with resin, aiming to reduce occlusal interferences and minimize the risk of fracture.

In cases where the pulp is exposed or nearly exposed, endodontic treatment may be necessary to prevent pulpal complications, such as pulpitis or pulpal necrosis. This can be achieved through pulp capping, pulpotomy, or root canal therapy [13], depending on the extent of pulpal involvement and the overall oral health of the patient.

Dental professionals should be aware of the potential presence of DE in their patients, as early detection and appropriate management are crucial in preventing complications and maintaining optimal oral health. Routine radiographic examinations and thorough clinical assessments contribute to timely diagnosis and treatment planning for individuals with this dental anomaly.

2.3.4.2.8 Hypoplasia

Is a dental condition characterized by inadequate deposition or mineralization of enamel or dentin during tooth formation [14, 15]. This developmental disturbance results in enamel defects that can appear as thin, pitted, or discolored areas on the tooth surface. In some cases, both enamel and dentin may be affected, leading to compromised tooth structure.

The affected teeth exhibit an increased susceptibility to caries, fracture, and wear due to the weakened and porous nature of the enamel and dentin. Hypoplasia can be localized, affecting only a single tooth, or it may involve multiple teeth in a generalized pattern. The severity of the defect can range from mild to severe, impacting both the primary and permanent dentitions.

There are various factors that contribute to the development of hypoplasia, including [14, 15]:

- Nutritional deficiencies: Inadequate intake of essential vitamins and minerals, such as calcium, phosphorus, and vitamins A, C, and D, can impair normal tooth development.

- Local trauma: Physical injury to the developing tooth or surrounding tissues may disrupt the normal formation of enamel and dentin.

- Systemic illness: Certain diseases, like celiac disease, rickets, or congenital syphilis, can adversely affect the process of tooth formation.

- Genetic factors: Some hereditary conditions, such as amelogenesis imperfecta and dentinogenesis imperfecta, can result in enamel and dentin defects.

Treatment for hypoplasia depends on the severity of the condition and focuses on restoring the function and aesthetics of the affected teeth while minimizing the risk of further complications. Interventions may include [15]:

- Topical fluoride application: Fluoride can help remineralize the enamel, reducing sensitivity and the risk of caries.

- Dental sealants: Sealants can protect the grooves and pits in the enamel from bacteria and plaque accumulation, preventing caries.

- Restorative materials: Composite resin or porcelain veneers can be used to restore the appearance and function of affected teeth.

- Prosthetic rehabilitation: In cases of severe enamel loss or multiple affected teeth, fixed or removable prostheses, such as crowns or dentures, may be necessary to restore function and aesthetics.

Early diagnosis and intervention are crucial for managing hypoplasia and preventing potential complications. Dental professionals should be aware of the various factors contributing to this condition and educate their patients on the importance of maintaining good oral hygiene and regular dental checkups.

2.3.4.2.9 Hypomineralization

Hypomineralization is a developmental defect that occurs during the maturation phase of enamel formation, leading to enamel with reduced mineral content and increased porosity [16]. This condition can affect both primary and permanent dentitions, often resulting in discolored, sensitive, and easily fractured teeth.

The exact etiology of this defect is not fully understood, but it is thought to involve genetic, environmental, and systemic factors that disrupt the process of enamel maturation. Some potential contributing factors include [16]:

- Genetic predisposition: Familial patterns have been observed in some cases of hypomineralization.

- Nutritional deficiencies: Insufficient intake of minerals and vitamins essential for enamel formation may play a role.

- Systemic illnesses: Fever, infections, or metabolic disorders during tooth development can disrupt enamel mineralization.

- Environmental factors: Exposure to certain chemicals, toxins, or medications may contribute to enamel defects.

Treatment depends on the severity of the condition and can be categorized into preventive, remineralizing, and restorative measures:

- Preventive care: Emphasizing good oral hygiene, regular dental checkups, and fluoride treatments can help maintain the integrity of affected teeth and prevent further damage.

- Remineralization therapy: The use of fluoride or calcium phosphate products, such as varnishes, gels, or mouth rinses, can help remineralize and strengthen the enamel, reducing sensitivity and the risk of caries.

- Restorative treatments: In more severe cases where the enamel structure is compromised, fillings or crowns may be necessary to restore the tooth's function, aesthetics, and integrity.

Early diagnosis and a tailored treatment plan are essential for managing hypomineralization and preventing complications, such as caries, tooth loss, or malocclusion. Dental professionals play a critical role in identifying this condition and implementing appropriate preventive and therapeutic strategies to ensure optimal oral health outcomes for patients.

2.3.4.2.10 Molar-incisor Hypomineralization (MIH)

MIH is a specific form of enamel hypomineralization that primarily affects permanent first molars and, in some cases, permanent incisors during early childhood [16]. The affected teeth exhibit demarcated opacities, posteruptive enamel breakdown, and atypical restorations. MIH is distinct from other enamel defects due to its characteristic distribution pattern and association with specific systemic conditions.

The precise etiology of MIH remains unclear, but it is believed to involve a combination of genetic, environmental, and systemic factors that disrupt the normal process of enamel maturation. Some potential contributing factors include [17]:

- Systemic illnesses: Fever, respiratory infections, or other childhood illnesses during the first few years of life may play a role.

- Nutritional deficiencies: Inadequate intake of minerals and vitamins essential for enamel formation could be a contributing factor.

- Genetic predisposition: A familial pattern has been observed in some cases, suggesting a possible genetic component.

Treatment for MIH depends on the severity of the condition and can be categorized into preventive, minimally invasive, restorative, and monitoring measures:

- Preventive measures: Regular dental checkups, fluoride treatments, and good oral hygiene practices can help maintain the integrity of affected teeth and prevent further damage.

- Minimally invasive techniques: Techniques such as resin infiltration or sealing can help stabilize the enamel and reduce sensitivity without significantly altering the tooth structure.

- Restorative treatments: In more severe cases where the enamel structure is compromised, restorative treatments like crowns, fillings, or composite resin may be necessary to restore the tooth's function, aesthetics, and integrity.

- Monitoring: Ongoing assessments help track the condition and ensure timely intervention when necessary.

Dental professionals play a critical role in identifying MIH, educating patients and caregivers, and implementing appropriate preventive and therapeutic strategies to ensure optimal oral health outcomes for young patients affected by this condition.

2.3.4.2.11 Clinical implications and treatment planning

Early detection and intervention are crucial for managing dental anomalies and their associated functional, aesthetic, and psychological impacts. A thorough understanding of these conditions and a tailored treatment approach can lead to improved quality of life and long-term oral health for affected patients. As dental professionals, it is essential to recognize these anomalies, provide appropriate preventive care, and develop individualized treatment plans to address the unique needs of each patient. By emphasizing early diagnosis and personalized care, clinicians can effectively manage these disorders and contribute to optimal oral health outcomes.

2.3.4.3 Anatomy and physiology of the oral cavity

2.3.4.3.1 Macroscopic anatomy

2.3.4.3.1.1 Teeth

Adult dentition consists of 32 teeth, divided into four classes— incisors, canines, premolars, and molars—each with distinct morphological features adapted for their specific roles in mastication. The functional surfaces of teeth (occlusal and incisal) are covered by a layer of enamel, the hardest tissue in the human body, providing strength and resistance to wear. The underlying dentin, cementum, and pulp tissues also contribute to the structural integrity and vitality of teeth, while periodontal ligaments anchor teeth within the alveolar bone [18].

2.3.4.3.1.2 Gingiva

Gingivae, or gums, are specialized mucosal tissues surrounding and supporting the teeth. Comprised of a keratinized epithelial layer, the gingiva provides a protective barrier against mechanical, chemical, and microbial insults. By forming a tight seal around the teeth, the gingiva prevents bacterial penetration into deeper tissues, maintaining periodontal health. A specialized fluid produced by the gingival sulcus, known as gingival crevicular fluid, plays a crucial role in host defense by providing nutrients to the periodontal tissues and facilitating the removal of bacteria and their byproducts [18].

2.3.4.3.1.2.1 The gingiva is comprised of two layers

- Epithelial layer: The epithelial layer of the gingiva is composed of stratified squamous epithelium, which acts as a protective barrier against mechanical, chemical, and microbial insults. The junctional epithelium, a specialized type of epithelium, forms a collar-like structure around the tooth and is responsible for creating a seal to prevent bacterial penetration [18].

- Connective tissue layer: The underlying connective tissue layer provides structural support to the gingiva and consists of collagen fibers, fibroblasts, blood vessels, and immune cells. This layer is essential for gingival health, as it supplies nutrients and facilitates the tissue's response to injury or infection [18].

2.3.4.3.1.3 Tongue

The muscular tongue is a versatile organ that plays a crucial role in various oral functions. Its intrinsic and extrinsic muscles enable complex movements necessary for the manipulation of food during mastication, as well as speech articulation and deglutition. The coordination of these muscles allows for precise and controlled actions of the tongue [18]. In addition to its motor functions, the tongue also harbors numerous papillae on its dorsal surface. These papillae contain taste receptors that are responsible for the perception of different gustatory stimuli, such as sweet, sour, bitter, salty, and umami flavors. The presence of these receptors on the tongue contributes to our ability to discern and enjoy the complex flavors in the food we consume [18].

2.3.4.3.1.4 Salivary glands

Three major pairs of salivary glands, namely the parotid, submandibular, and sublingual glands, synthesize and secrete saliva, a complex fluid containing water, electrolytes, mucus, enzymes, and various antibacterial and antiviral factors. Salivary secretion is a highly regulated process mediated by the parasympathetic and sympathetic nervous systems, which control the volume and composition of saliva in response to various stimuli [18]. Each salivary gland contributes uniquely to the overall composition of saliva. The parotid glands produce a serous, watery secretion rich in enzymes like salivary amylase, which initiates carbohydrate digestion. The submandibular glands secrete a mixed serous and mucous saliva, providing both enzymatic and lubricating properties. The sublingual glands primarily produce mucous saliva, which aids in lubricating the oral cavity and facilitating swallowing. Saliva plays a vital role in maintaining optimal oral health by lubricating the oral cavity, aiding in taste perception, facilitating speech, and providing a protective barrier against microbial colonization and biofilm formation. The continuous secretion and flow of saliva help wash away food debris, neutralize acids, and prevent demineralization of the teeth [18].

2.3.4.3.2 Microscopic anatomy

At the microscopic level, the tooth and oral cavity tissues are composed of various cell types, including the protective squamous epithelial cells of the gingiva, the odontoblasts that create dentin, and the ameloblasts that form enamel [19]. Understanding this structure allows for more effective management of clinical issues such as caries, periodontal disease, and oral infections.

2.3.4.3.2.1 Enamel

As the outermost layer of the tooth, enamel serves as a protective barrier against mechanical wear, temperature fluctuations, and microbial invasion. Composed primarily of hydroxyapatite crystals arranged in rods or prisms, enamel exhibits exceptional strength and durability. However, once formed, enamel cannot regenerate, making the prevention of enamel erosion and caries crucial.

2.3.4.3.2.2 Dentin

Situated beneath the enamel layer, dentin comprises the majority of the tooth structure and acts as a shock absorber during chewing. Dentin contains a network of microscopic tubules housing sensory nerve fibers from the pulp. The formation of dentin begins with the differentiation of dentin-forming cells called odontoblasts, which secrete the dentin matrix, resulting in the initial layer of dentin known as primary dentin or mantle dentin. Primary dentin is located in the outermost layer of dentin, just beneath the enamel and cementum.

As a living tissue, dentin can undergo continuous remodeling, with the deposition of secondary and tertiary dentin to provide an additional protective layer against external insults. Secondary dentin is formed after root completion and continues to develop throughout life at a slower rate than primary dentin, while tertiary dentin is produced in response to external stimuli, such as caries or tooth wear.

2.3.4.3.2.3 Pulp Tissue

The pulp, residing in the innermost chamber of the tooth, is a highly vascularized and innervated tissue. Pulp cells, including odontoblasts, fibroblasts, and immune cells, are responsible for maintaining the tooth's vitality, generating new dentin, and participating in the tooth's defensive responses to injury or infection.

2.3.4.3.2.4 Periodontal Ligament (PDL)

Composed of fibrous connective tissue, the PDL connects the cementum of the tooth root to the alveolar bone. The PDL's unique architecture allows for tooth movement under physiological masticatory forces and aids in proprioception. Its fibroblasts and collagen fibers play essential roles in remodeling and maintaining periodontal tissue integrity.

2.3.4.3.2.5 Gingiva

The gingiva's epithelial layer consists of stratified squamous epithelium, which is composed of several cell types, including keratinocytes, melanocytes, and Langerhans cells. These cells contribute to the barrier function and immune surveillance of the gingiva [19].

The connective tissue layer is a fibrous network of collagen fibers, fibroblasts, blood vessels, and immune cells. This layer not only provides structural support but also enables the tissue's response to injury or infection. Key cellular components include:

- Fibroblasts: These cells synthesize collagen fibers and other extracellular matrix components, maintaining the structural integrity of the connective tissue.

- Immune cells: Macrophages, lymphocytes, and other immune cells play a crucial role in detecting and eliminating pathogens, as well as modulating inflammation within the gingival tissue.

- Blood vessels: The rich vascular network within the connective tissue layer ensures an adequate supply of nutrients and oxygen to the gingival tissue, promoting its health and functionality.

2.3.4.3.3 Oral mucosa

The oral mucosa is the mucous membrane lining the inside of the mouth, consisting of epithelium and underlying connective tissue (lamina propria) [20]. It plays a crucial role in maintaining oral health, facilitating speech and swallowing, and acting as a protective barrier against mechanical, chemical, and microbial insults. The oral mucosa can be divided into three types based on its location and function [20]:

2.3.4.3.3.1 Lining mucosa

Located on the inner cheeks, lips, and ventral surface of the tongue, the lining mucosa is more flexible and elastic, providing protection against friction and trauma during speech and mastication.

2.3.4.3.3.2 Masticatory mucosa

Found on the gingiva and hard palate, the masticatory mucosa is keratinized and tightly bound to underlying structures, which provides better resistance to mechanical stress during activities like chewing. This toughness enables it to withstand the frictional forces exerted on the mouth's tissues during mastication.

2.3.4.3.3.3 Specialized mucosa

This type is located on the dorsum of the tongue, taste buds, and salivary gland orifices. It serves specific functions related to taste, speech, and secretion. The specialized structures of the tongue and taste buds play a central role in the perception of taste stimuli, while the mucosal surface is adapted to interact with saliva and other oral substances.

2.3.4.3.3.4 Functions of the oral mucosa

The oral mucosa plays a critical role in maintaining oral health and overall well-being through its multifaceted functions:

2.3.4.3.3.4.1 Protective barrier

The oral mucosa serves as a physical barrier, protecting underlying tissues from mechanical, chemical, and microbial insults. The stratified squamous epithelium and the basement membrane provide structural integrity, preventing harmful substances and pathogens from infiltrating deeper tissues.

2.3.4.3.3.4.2 Lubrication and moisture

The secretion of mucus helps maintain a moist environment within the oral cavity, which is essential for facilitating speech, swallowing, and the movement of food during mastication. The lubricating properties of mucus reduce friction and protect the oral tissues from mechanical trauma during eating, speaking, and other movements.

2.3.4.3.3.4.3 Sensory perception

The oral mucosa contains numerous sensory nerve endings that contribute to the perception of pressure, temperature, taste, and pain. This sensory input is crucial for proper oral functions, such as chewing, swallowing, and speech. The detection of pain and temperature helps protect oral tissues from potential injury by identifying harmful stimuli or substances.

2.3.4.3.3.4.4 Immune defense

An integral component of the oral immune system, the oral mucosa contains immune cells such as Langerhans cells and intraepithelial lymphocytes. These cells recognize and respond to potential threats, helping defend the body from infections. Furthermore, antimicrobial substances like defensins and lysozyme in saliva assist in controlling oral microbial populations, contributing to a balanced oral microbiota.

2.3.4.3.3.4.5 Wound healing

The oral mucosa exhibits an exceptional ability to repair and regenerate itself after injury. The rapid turnover of epithelial cells, coupled with the presence of growth factors in saliva, allows for quick healing of oral wounds. This efficient healing process is crucial to maintaining the integrity of the oral tissues after trauma or injury.

2.3.4.4 Common conditions affecting oral mucosa

2.3.4.4.1 Oral candidiasis

Oral candidiasis is a fungal infection affecting the oral mucosa, caused primarily by an overgrowth of the yeast-like organism *Candida albicans*. It is essential to understand the various factors contributing to this condition and recognize its different clinical presentations for effective diagnosis and treatment [21].

Cause: Oral candidiasis is primarily caused by *Candida albicans*, a yeast-like organism that is typically part of the normal oral microbiota. Overgrowth of *Candida* can occur under various conditions, such as immunosuppression, the use of antibiotics, poor oral hygiene, or the presence of underlying health conditions [22].

Presentation: Oral candidiasis can manifest in several forms, including:

- *Pseudomembranous candidiasis (thrush)*: White, cottage cheese-like plaques that can be scraped off easily, revealing an erythematous base underneath.

- *Erythematous candidiasis*: Red, raw patches, often located on the palate or dorsum of the tongue, indicating inflammation.

- *Hyperplastic candidiasis*: Thick, white lesions that cannot be scraped off and are typically found on the buccal mucosa or tongue.

- *Angular cheilitis*: Fissuring, erythema, and crusting at the corners of the mouth, often seen in combination with other forms of candidiasis.

Treatment: Oral candidiasis is treated with topical or systemic antifungal medications, such as nystatin or fluconazole. Addressing underlying conditions or predisposing factors, along with proper oral hygiene practices, can help prevent recurrence and maintain a balanced oral microbiota.

2.3.4.4.2 Lichen planus

Oral lichen planus (OLP) is a chronic inflammatory condition affecting the oral mucosa, with a prevalence rate of approximately 1–2% in the general population. The exact cause remains unclear; however, several factors are thought to contribute to its development [23].

Cause: OLP is considered an autoimmune condition, where the immune system mistakenly attacks the epithelial cells of the oral mucosa. This immune-mediated response results in the characteristic clinical manifestations observed in affected individuals [24].

Presentation: Oral lichen planus can appear in various forms:

- Reticular form: Characterized by lacy, white lines or patches (Wickham's striae), which may be asymptomatic or cause mild discomfort. This form is less likely to transform into malignancy.

- Erosive form: Involves painful, ulcerated lesions surrounded by erythema, which can cause discomfort and sensitivity. This form is prone to secondary infections and may require more intensive management.

- Atrophic form: Characterized by thinning or reddening of the oral mucosa, leading to a burning sensation and difficulty eating. It carries a higher risk of malignant transformation, necessitating regular follow-ups.

- Note: Oral lichen planus can also present in mixed forms, and its clinical manifestations can vary significantly among individuals. Accurate diagnosis and management are essential.

2.3.4.4.2.1 Pharmacological treatments for OLP

These aim to manage symptoms and reduce the risk of malignant transformation [25]:

- Topical Corticosteroids (TCS): These are the first-line treatment for symptomatic OLP. They reduce inflammation and provide relief from discomfort.

- Topical calcineurin inhibitors (e.g., tacrolimus): Used when topical corticosteroids are ineffective. They can help reduce inflammation and improve symptoms, usually as a short-term treatment option.

- Systemic corticosteroids: Reserved for severe or extensive cases, though their side effects—such as increased susceptibility to infections, weight gain, glucose intolerance, and osteoporosis—must be carefully considered.

- Retinoids: These synthetic forms of vitamin A help reduce inflammation but may cause side effects like increased cholesterol, dry skin, and liver damage.

- Immunosuppressive agents: For severe or recalcitrant cases, immunosuppressive drugs may be required. However, these agents have considerable side effects, such as increased infection risk, liver damage, and bone marrow suppression.

2.3.4.4.2.2 Non-pharmacological treatments for OLP

In addition to medication, non-pharmacological treatments focus on alleviating discomfort [26]:

- Symptomatic relief: Patients should avoid irritants like spicy or acidic foods, use a soft-bristled toothbrush, and maintain good oral hygiene to minimize irritation.

- Adjunctive therapies: Techniques such as low-level laser therapy can be used alongside other treatment options to provide symptomatic relief.

- Dietary modifications: A diet rich in antioxidants and omega-3 fatty acids may help reduce inflammation associated with OLP.

- Multidisciplinary approach: Collaborating with other healthcare providers, such as dermatologists and nutritionists, can be beneficial in managing OLP. A holistic approach may help achieve optimal outcomes for patients.

2.3.4.4.3 Oral cancers

Oral cancers pose a significant concern in dental care, impacting patients' overall health. Early detection, understanding risk factors, and recognizing signs are vital for effective intervention. Dental professionals play an integral role in diagnosing and managing oral cancers, given their expertise in the oral cavity [27].

2.3.4.4.3.1 Causes

Oral cancer can result from several factors, with the following considered significant risk factors [27, 28]:

- *Tobacco use*: Smoking or using smokeless tobacco products is strongly linked to an increased risk of oral cancer [29].

- *Alcohol consumption*: Heavy and chronic alcohol use further increases the risk, especially in combination with tobacco use.

- *Human Papillomavirus (HPV)*: Particularly HPV type 16, associated with oropharyngeal cancers, has emerged as a significant contributor [30].

- *Nutritional factors*: A diet low in fruits and vegetables may contribute to an increased risk of developing oral cancers due to a lack of protective nutrients.

- *Other potential causes*: Chronic irritation (e.g., poorly fitting dentures or rough teeth), poor oral hygiene, and genetic predisposition may also play a role.

2.3.4.4.3.2 Presentation

Oral cancer can present with various signs and symptoms. Dental professionals should watch for the following indicators [31]:

- *Nonhealing ulcers*: Lesions that become indurated (hardened), infiltrated, or bleed, persisting for more than 2 weeks.

- *Red, white, or mixed patches*: Lesions that may appear as leukoplakia (white) or erythroplakia (red), or a combination of both, in the oral mucosa.

- *Pain and tenderness*: Persistent pain, discomfort, or numbness in the oral cavity that may indicate malignancy.

- *Difficulties in swallowing, chewing, or speaking*: A sign that the cancer might be affecting nearby structures, such as muscles and nerves.

- *Lymphadenopathy*: Enlarged lymph nodes, particularly in the cervical region, which may indicate metastatic spread.

2.3.4.4.3.3 Diagnosis and advanced detection

Early detection of oral cancers heavily relies on routine oral examinations conducted by dental professionals. Advanced diagnostic tools, such as autofluorescence imaging, biopsy, and histopathological analysis, have greatly improved the ability to identify premalignant lesions and invasive cancers at an early stage. These advancements are essential in aiding prognosis and tailoring effective treatment strategies [32].

2.3.4.4.3.4 Treatment

The treatment for oral cancer depends on the cancer's stage and location. A multidisciplinary approach is essential to ensure comprehensive care, with involvement from oral surgeons, oncologists, radiologists, pathologists, dentists, and other specialists [33]. Treatments may include:

- *Surgery*: The primary goal is to remove the tumor along with a margin of healthy tissue. The type of surgery varies depending on the tumor's size, stage, and location. In some cases, reconstructive surgery may be necessary to restore the function and appearance of the affected area.

- *Radiation therapy*: High-energy radiation beams target and kill cancer cells or shrink tumors. Radiation therapy is often used as a primary treatment or in combination with surgery and chemotherapy.

- *Chemotherapy*: Chemotherapy is a systemic treatment that involves using drugs to kill cancer cells throughout the body. It is usually combined with surgery and radiation, particularly in advanced stages, or as palliative care when cure is not achievable.

- *Other treatments*: Targeted drug therapy and immunotherapy are newer approaches tailored to individual patients and the unique genetic characteristics of the cancer, offering additional options for treating oral cancers.

2.3.4.4.3.5 Prevention and the role of dental professionals

Preventive strategies against oral cancers primarily involve addressing modifiable risk factors, which include:

- Smoking cessation: Quitting smoking reduces the risk of oral cancers and benefits overall health.

- Limiting alcohol consumption: Reducing alcohol intake, especially in combination with smoking cessation, can help minimize the risk of developing oral cancer.

- HPV vaccination: Vaccines against high-risk strains of HPV are available and can potentially reduce the incidence of HPV-associated oral cancers.

- Nutritional counseling: Promoting a balanced diet, rich in fruits and vegetables, may contribute to a reduced risk of oral cancers by providing essential nutrients and antioxidants.

Dental professionals play a vital role in raising oral cancer awareness and conducting thorough examinations to identify suspicious lesions for further evaluation [34]. By educating patients about risk factors, emphasizing the importance of regular checkups, and promoting preventive strategies, dental professionals serve as a frontline defense in the early detection and prevention of oral cancers.

2.3.4.4.3.6 Importance of early detection

Early detection of oral cancers is crucial for improving the prognosis and treatment success. Regular dental checkups, self-examinations, and screenings by dental professionals are vital for identifying suspicious lesions in their early stages. Any suspicious findings should be promptly followed up with a referral to specialists for further evaluation and care.

Timely recognition of oral cancer signs, combined with early intervention, significantly enhances the chances of successful treatment and recovery. Furthermore, early detection helps reduce the strain on healthcare systems caused by advanced-stage treatment requirements and long-term rehabilitative care. By emphasizing the importance of early detection, dental professionals can encourage patients to take a proactive approach to oral cancer prevention and overall oral health.

2.3.4.5 Tooth development and eruption (odontogenesis)

Tooth development is a highly regulated process that starts early in embryonic development and continues throughout childhood. This process involves the formation of both primary and permanent teeth, which arise from specialized oral tissues. Any disruption in odontogenesis can result in congenital dental anomalies, making the understanding of these stages crucial for oral health management [35].

2.3.4.5.1 Stages of tooth development

Tooth development can be divided into several stages, each with distinct morphological and cellular changes.

2.3.4.5.1.1 Bud stage

- Initiation: The process starts with the development of the dental lamina, a band of epithelial tissue from the oral ectoderm, which forms tooth buds.
- Proliferation: Cell proliferation and differentiation lead to the formation of the enamel organ, which consists of the inner enamel epithelium, outer enamel epithelium, and stellate reticulum.
- Gene expression: Key genes such as Pax9 and Msx1 drive the development process during the bud stage [36].

2.3.4.5.1.2 Cap stage

- Enamel organ formation: The enamel organ forms a cap-like structure, comprising the outer and inner enamel epithelia, surrounding the dental papilla.
- Differentiation of odontoblasts: Cells in the dental papilla differentiate into odontoblasts, which later produce dentin.
- Development of the dental follicle: Surrounding ectomesenchyme gives rise to the dental follicle, which will develop into cementoblasts and periodontal ligament cells.

2.3.4.5.1.3 Bell stage

During this stage, the enamel organ undergoes significant morphological changes:

- Morphological changes: The enamel organ takes on a bell-shaped appearance as tooth development continues.
- Differentiation of ameloblasts and odontoblasts: Ameloblasts develop from the inner enamel epithelium, producing enamel, while odontoblasts from the dental papilla produce dentin.
- Hard tissue formation: The dentino-enamel junction forms, marking the interface between enamel and dentin, as enamel, dentin, and cementum are deposited.

2.3.4.5.2 Eruption timelines

Tooth eruption is a physiological process involving the intricate interaction of genetic, molecular, and environmental factors. It plays a critical role in the development of the dentition, with the timing and sequence of eruption reflecting the tooth germ's development and systemic influence.

Deviation from typical eruption patterns can indicate developmental or systemic issues. Therefore, tracking eruption sequences is crucial for identifying conditions like delayed eruption, impaction, and ectopic eruption. Monitoring these patterns also supports pediatric dentistry and orthodontic planning, ensuring appropriate interventions and optimal oral health outcomes (**Table 1**) [37].

2.3.4.5.2.1 Factors affecting tooth eruption

a. Genetics

Genetic factors play a crucial role in determining the number, size, and eruption patterns of teeth. Genetic syndromes and specific genes can significantly impact dental development and tooth eruption. Genetic syndromes, such as cleidocranial dysplasia and ectodermal dysplasia, are associated with various dental abnormalities, including delayed or failed tooth eruption. Additionally, specific genes like PAX9, MSX1, and TGFA contribute to the initiation and progression of tooth development, with mutations potentially leading to tooth agenesis, delayed eruption, or other dental issues [36]. Some examples of these genetic influences include [38]:

Cleidocranial dysplasia: This condition affects the development of bones and teeth, often resulting in delayed or failed tooth eruption, supernumerary teeth, and other dental abnormalities.

Ectodermal dysplasia: Affecting the development of ectodermal tissues, this syndrome can cause missing teeth, abnormal tooth shapes, and delayed eruption.

Specific genes:

Certain genes play a critical role in the development and eruption of teeth. Genetic mutations or abnormalities in these genes can lead to various dental issues, including delayed eruption, tooth agenesis, and other abnormalities. Key genes involved in tooth development are:

- PAX9: This gene is involved in tooth morphogenesis and plays a critical role in the initiation and progression of tooth development. Mutations in PAX9 can lead to tooth agenesis or failure of tooth eruption [36].

Teeth	Primary dentition	Permanent dentition
Central incisors	8–12 months	6–7 years
Lateral incisors	9–13 months	7–8 years
Canines	16–22 months	9–13 years
First molars	13–19 months	6–7 years
Second molars	25–33 months	11–13 years
Premolars	—	10–12 years
Third molars (wisdom teeth)	—	17–21 years (may not erupt)

Table 1.
Eruption timeline for primary and permanent dentition.

- MSX1: This gene is essential for the proper development and eruption of teeth, particularly molars. Mutations in MSX1 can result in delayed or failed tooth eruption, as well as other dental abnormalities [36].
- TGFA: The transforming growth factor alpha (TGFA) gene regulates the development and differentiation of dental tissues. Abnormalities in this gene may impact tooth eruption and formation [38].

b. Nutrition

This plays a vital role in tooth development and eruption. Adequate intake of essential nutrients is crucial for ensuring proper dental health [39]. Nutritional deficiencies and excess consumption can impact tooth development and eruption:

- Deficiencies:
  - *Vitamin D*: Inadequate vitamin D can lead to delayed eruption, enamel hypoplasia, and other dental developmental issues [40].
  - *Calcium and phosphorus*: Deficiencies in these minerals can result in delayed eruption, poor mineralization, and increased susceptibility to dental caries [39].
- Excess consumption:
  - *Sugar consumption*: High sugar intake promotes the growth of cariogenic bacteria, which produce acids that demineralize enamel and dentin. This can potentially impact eruption patterns and increase the risk of dental caries [39].

Overall, balanced nutrition is essential for promoting healthy tooth development and ensuring proper eruption. Maintaining an appropriate intake of vital nutrients like vitamin D, calcium, and phosphorus while limiting excessive sugar consumption can contribute to optimal dental health and help prevent potential issues with tooth eruption.

c. Systemic conditions

Various health conditions and treatments can affect tooth eruption [41]:

- Diseases: Certain diseases may lead to delayed eruption, dental defects, or increased susceptibility to infections. These include:
  - *Diabetes*: Uncontrolled blood sugar levels can lead to delayed tooth eruption, increased risk of infections, and periodontal disease.
  - *Celiac disease*: Malabsorption of nutrients in individuals with celiac disease can result in enamel defects, delayed eruption, and other dental issues.
  - *Congenital syphilis*: This condition can cause characteristic dental abnormalities, including Hutchinson's teeth, mulberry molars, and delayed eruption.

- Hormonal imbalances: Hormonal imbalances, such as hypothyroidism and hyperthyroidism, can also affect dental development and eruption patterns:
    - *Hypothyroidism*: Low thyroid hormone levels can delay tooth eruption and impact dental development.
    - *Hyperthyroidism*: Excessive thyroid hormone production can lead to accelerated tooth eruption and other dental abnormalities.
- Medications: Certain medications, such as chemotherapy and radiation therapy, can adversely affect tooth development and eruption:
    - *Chemotherapy and radiation therapy*: These cancer treatments can lead to delayed eruption, agenesis, or other dental abnormalities.

d.Local factors

Direct local factors: These have a more immediate and physical impact on tooth eruption, involving the presence of specific structures or conditions within the immediate area of the dental arch that can directly impede or influence the eruption process:

- Supernumerary teeth: These can significantly impact the eruption of adjacent teeth, often leading to delayed or ectopic eruption. Early detection and management are essential for proper dental development and occlusion.
- Crowding: Insufficient space within the dental arch can result in delayed eruption or ectopic eruption of teeth. Early orthodontic intervention can help manage crowding and promote optimal eruption patterns [42].
- Dental trauma or infections: Trauma or infections affecting the teeth or surrounding structures may interfere with the eruption process. Prompt diagnosis and management can minimize their impact on dental development [43].
- Prolonged thumb sucking or pacifier use: Persistent nonnutritive sucking habits can contribute to dental and skeletal changes, potentially causing delayed eruption or misalignment of teeth. Appropriate guidance and interventions should be provided to address these habits [44].
- Tongue thrusting: Chronic tongue thrusting can lead to dental issues and altered eruption patterns. Assessment and management of orofacial myofunctional disorders are important components of comprehensive dental care [45].

Indirect local factors: These factors contribute to the overall environment within the oral cavity, which can indirectly affect tooth eruption:

- Maintenance of healthy periodontal tissues: Proper oral hygiene is essential for the normal eruption process within the local oral environment. Inflammation or infection in the gingivae can impede or delay tooth eruption [46].

- Prevention of dental caries: Good oral hygiene practices, such as brushing and flossing, help prevent dental caries. Severe caries in deciduous teeth can lead to premature tooth loss, affecting the eruption pattern of permanent teeth [47].

- Preservation of space for permanent teeth: Maintaining healthy periodontal tissue and practicing proper oral hygiene can help preserve the necessary space for permanent teeth to erupt in the correct position within the local dental arch. Loss of space due to periodontal disease or premature tooth loss can lead to malocclusion and other eruption-related issues [47].

Socioeconomic status

- **Oral hygiene practices*: Socioeconomic factors can influence oral hygiene practices and habits. Limited access to proper dental care and education may result in poor oral hygiene, which can contribute to periodontal disease, tooth decay, and other issues that can affect tooth eruption [48].

- **Nutrition*: Socioeconomic status can also impact one's diet and nutrition. A diet high in sugar and refined carbohydrates, often associated with lower socioeconomic status, can increase the risk of dental caries and affect dental health, including tooth eruption.

2.3.4.6 Common oral health conditions

2.3.4.6.1 Dental caries

Dental caries, often referred to as tooth decay or cavities, is one of the most widespread chronic diseases worldwide. It results from a combination of dietary sugars and the microbial activity of specific acid-producing bacteria in the oral cavity, particularly *Streptococcus mutans* and Lactobacillus species [48].

When these bacteria metabolize carbohydrates, they generate acidic byproducts, which lower the pH of the mouth and cause the demineralization of enamel. If left unchecked, caries progresses to the underlying dentin, causing damage and potentially reaching the tooth's pulp, leading to infection.

Clinical management

- The clinical management of dental caries depends on its severity and involves removing decayed portions of the tooth, followed by restoration with materials that suit the affected areas.

- The aim is to be as minimally invasive as possible, with a range of materials available, such as amalgam and tooth-colored or composite restorations. However, the use of amalgam has been discontinued in Europe [49].

- Endodontic treatments and/or indirect restorations may be required for more advanced cases, particularly when the caries has reached the pulp or caused significant damage to the tooth structure.

Prevention strategies

- Regular brushing with fluoride toothpaste to enhance remineralization and prevent the formation of caries.
- Dietary changes, particularly reducing carbohydrate intake, to minimize the formation of acidic byproducts.
- The use of dental sealants to protect the tooth surface from bacterial attack, particularly in children's molars.
- Regular professional checkups to ensure early detection and management of dental caries.

2.3.4.6.2 Periodontal diseases

Periodontal diseases, affecting the tissues surrounding and supporting the teeth, are characterized by inflammation and damage to the gingiva, periodontal ligament, and alveolar bone. If left untreated, they can lead to tooth loss and other systemic health issues [50].

Stages of periodontal disease:

1. *Gingivitis*: The early stage of periodontal disease, caused by the accumulation of bacterial plaque on the gingivae, leading to inflammation, bleeding, and discomfort.
2. *Periodontitis*: If not treated, gingivitis can progress to periodontitis, a more severe form of gingival disease that affects the soft and hard tissues supporting the teeth, resulting in the resorption of bone and potential tooth mobility or loss.

Risk factors:

- Smoking: Smoking weakens the immune system, making it difficult for the body to fight off periodontal infections and impeding healing.
- Diabetes: Uncontrolled diabetes increases the risk of developing periodontal diseases, as high blood sugar levels promote bacterial growth and impair healing.
- Poor oral hygiene: Inadequate dental care allows bacteria to accumulate and form plaque, leading to inflammation and disease.

Treatment options:

- Scaling and Professional Mechanical Plaque Removal (PMPR): Initial treatment typically involves removing plaque and tartar from above and below the gum line, followed by regular maintenance to prevent recurrence.
- Surgical interventions: Advanced cases may require procedures such as gingival grafts or flap surgery to restore the attachment of the gingiva to the teeth.

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2.3.4.6.3 Tooth wear

Refers to the cumulative loss of tooth substance due to various mechanical or chemical factors throughout an individual's lifetime [51]. This section will discuss the types of tooth wear, risk factors, preventive strategies, restorative management approaches, and monitoring process.

2.3.4.6.3.1 Types of tooth wear

Attrition: Wear caused by tooth-to-tooth contact during mastication or parafunctional habits like bruxism.

- Abrasion: Wear caused by external mechanical forces, such as aggressive brushing, improper use of dental floss, or habits like nail-biting.
- Erosion: Wear caused by exposure to acids from extrinsic or intrinsic sources, such as acidic foods and beverages or gastroesophageal reflux disease.
- Abfraction: Wear caused by biomechanical loading and tensile stresses, often seen as wedge-shaped cervical lesions near the cementoenamel junction.

2.3.4.6.3.2 Risk factors

- Poor oral hygiene practices: Inadequate or aggressive brushing techniques, improper use of dental floss, and lack of regular professional cleanings can contribute to tooth wear [52].
- Diet: Excessive consumption of acidic foods and beverages can erode tooth enamel, leading to tooth wear.
- Parafunctional habits: Habits such as bruxism (teeth grinding) and clenching can cause wear due to excessive mechanical forces.
- Gastroesophageal reflux disease (GORD): The regurgitation of stomach acids into the mouth can contribute to tooth erosion.
- Occupational exposures: Workers exposed to abrasive materials or acidic substances in their work environment may experience increased tooth wear.

2.3.4.6.3.3 Preventive strategies

To minimize the risk of developing Tooth Surface Loss (TSL) and halt its progression, it is crucial to identify the underlying cause and adopt appropriate preventive measures. These strategies may include [51]:

- Accurate diagnosis: Determine the specific type of tooth wear causing TSL (attrition, abrasion, erosion, or abfraction) to develop an appropriate management plan.
- Maintain proper oral hygiene practices: Encourage gentle brushing techniques, proper use of dental floss, and regular professional cleanings to minimize tooth wear.

- Encourage a balanced diet: Limit the intake of acidic foods and beverages and promote a well-balanced diet to maintain optimal oral health.

- Address parafunctional habits: Implement strategies such as the use of occlusal splints, stress management, and relaxation techniques to help manage bruxism and clenching.

- Identify occupational exposures: Encourage patients with occupations that involve exposure to abrasive materials or acidic substances to follow appropriate safety measures and consult their dentist for personalized guidance on minimizing tooth wear. Examples of occupations with increased exposure include professional athletes and those who work in the food and beverage industry.

- Manage underlying medical conditions: Treat or control conditions such as GORD to reduce the occurrence of acid reflux and minimize its impact on oral health. Address stress and anxiety through various techniques such as mindfulness, relaxation exercises, or seeking professional help, as they can contribute to parafunctional habits that cause tooth wear.

2.3.4.6.3.4 Restorative management

Direct restorations: Composite resin to rebuild the lost tooth structure, often used for minor to moderate cases of tooth wear [53, 54].

Ceramic veneers, onlays, or crowns are used to reestablish the anatomical form, function, and esthetics of the affected teeth, typically reserved for more extensive or severe cases of tooth wear. In such cases, a referral to a specialist, such as a prosthodontist or an experienced restorative dentist, may be necessary to ensure optimal treatment outcomes and comprehensive care [53, 54].

2.3.4.6.3.5 Regular dental visits, monitoring, and follow-ups

Emphasize the importance of regular dental checkups for early detection and intervention of tooth wear, allowing for appropriate management and treatment. Identify the type of tooth wear causing TSL to provide more tailored preventive advice and effectively manage each wear type.

2.3.4.6.3.6 Monitoring and assessment of tooth wear

Monitoring tooth wear progression is essential for effective management and timely intervention. Various methods can be employed to assess and track tooth wear over time [55], including:

2.3.4.6.3.6.1 Clinical assessment

- Tooth wear indices: Utilize standardized indices, such as the Basic Erosive Wear Examination (BEWE), to classify the severity of wear based on clinical examination findings. This provides a consistent method for tracking changes over time.

- Clinical photographs: Take standardized photographs at regular intervals to visually assess and document any progression of tooth wear. These images can help in planning further interventions.

- Silicon putty index: Use silicon putty impressions to directly measure tooth wear, allowing for the monitoring of subtle changes over time.

2.3.4.6.3.6.2 Digital assessment

- Intraoral scanners: These devices provide highly accurate 3D scans of the dentition, which can be used to monitor and document tooth wear. The digital data allows for easy comparison over time [55].

- Study models: Traditional or digital study models can serve as accurate baselines for assessing tooth wear progression by capturing the dental condition at a specific point in time [55]. Digital study models offer the advantage of easier comparison for future assessments.

2.3.4.6.3.7 Follow-up and ongoing management

Encourage patients to attend follow-up appointments for monitoring any signs of tooth wear progression, ensuring timely intervention and management. Implement periodic evaluations of parafunctional habits, psychological factors, and overall oral health to assess the effectiveness of preventive strategies and make adjustments as needed. Monitoring these factors will ensure the continued success of preventive approaches and help tailor ongoing tooth wear management.

2.3.4.6.4 Oral infections

Oral infections can range from simple and treatable conditions to severe systemic concerns. These infections are caused by bacteria, fungi, and viruses and can present a significant risk to both oral and overall health if not properly managed. Infections in the mouth can also have a profound effect on eating, speaking, and overall quality of life.

Types of oral infections [56]:

- Fungal infections: Oral candidiasis (thrush) is one of the most common fungal infections in the mouth.

- Viral infections: Examples include herpes simplex virus (cold sores) and human papillomavirus (HPV) infections.

- Bacterial infections: These include conditions such as periodontitis, dental abscesses, and gingivitis.

2.3.4.6.4.1 Oral candidiasis (thrush)

Oral candidiasis is caused by the overgrowth of *Candida albicans*, a yeast species that normally resides in the mouth [57].

Risk factors:

- Weakened immune systems: Individuals with HIV/AIDS, cancer patients undergoing chemotherapy, diabetics, or those using certain medications like corticosteroids or antibiotics are more susceptible.

Symptoms:

- White patches on the tongue, cheeks, gingivae, or palate, which may be painful, especially when scraped.
- A burning or sore sensation in the mouth.

Management:

- Antifungal medications like nystatin or fluconazole are often prescribed.
- For mild cases, regular oral hygiene and a balanced diet can help prevent Candida overgrowth.

2.3.4.6.4.2 Herpes Simplex Virus (HSV): oral herpes (cold sores)

HSV-1 is the primary cause of oral herpes, although HSV-2 can also cause oral infections in some cases [58].

- *Symptoms*: Painful blisters usually appear around the lips, gingivae, or the roof of the mouth. Cold sores typically recur due to triggers such as stress, illness, or sun exposure.
- *Management*: Antiviral medications like acyclovir or valacyclovir help reduce the severity and frequency of outbreaks. Supportive treatments like topical ointments or creams can alleviate pain.
- *Prevention*: Avoid close contact with infected individuals during outbreaks and practice good hygiene.

2.3.4.6.4.3 Bacterial infections

2.3.4.6.4.3.1 Dental abscess (periapical abscess)

Caused by bacterial infections, often resulting from untreated dental caries, an abscess forms near the tip of the tooth root. Common pathogens include Streptococcus and Prevotella species [59].

- *Risk factors*: Poor oral hygiene, advanced gum disease, tooth injury, or untreated cavities increase the risk of developing a dental abscess.
- *Symptoms*: Severe throbbing tooth pain, swelling in the face or jaw, fever, and pus discharge.
- *Management*: Drainage of the abscess, along with root canal therapy or tooth extraction, may be necessary. Antibiotics like penicillin or clindamycin are used to manage the bacterial infection.

2.3.4.6.4.3.2 Acute Necrotizing Ulcerative Gingivitis (ANUG)

- Cause: This painful, destructive gingival infection primarily involves a synergistic infection of Fusobacterium, *Prevotella intermedia*, and spirochetes [59].

- Risk factors: Stress, poor oral hygiene, smoking, and malnutrition can trigger ANUG. It often occurs in young adults and can be exacerbated by underlying systemic conditions, such as HIV/AIDS.
- Symptoms: Painful, bleeding gums develop ulcers and a grayish appearance. A foul odor often accompanies these symptoms.
- Management: Effective treatment involves professional dental cleaning to remove plaque and tartar, along with antimicrobial mouth rinses. Antibiotic therapy, often metronidazole, may be required for more severe cases.

2.3.4.6.4.3.3 Periodontal abscess

- Cause: Periodontal abscess is a bacterial infection that occurs in the tissues surrounding a tooth, often associated with gum disease. It results from the accumulation of bacteria in the periodontal pockets [59].
- Risk factors: Poor oral hygiene, smoking, or a history of periodontal disease increase the likelihood of periodontal abscess formation.
- Symptoms: Severe pain, gum swelling, pus drainage from the abscess, and tooth sensitivity are common symptoms.
- Management: Thorough professional cleaning and drainage of the abscess are necessary. Antibiotics may be prescribed if there is significant tissue involvement or systemic symptoms.

2.3.4.6.4.3.4 Ludwig's angina

- Cause: Ludwig's angina is a severe, life-threatening bacterial infection affecting the floor of the mouth. It generally stems from an infected tooth or tonsil, leading to the spread of infection to the neck and soft tissues [60].
- Risk factors: Poor dental hygiene, untreated dental infections, and preexisting conditions like diabetes or immunocompromised states can increase the risk of developing Ludwig's angina.
- Symptoms: Swelling of the neck and floor of the mouth, pain in the mouth, difficulty swallowing, and sometimes difficulty breathing. Fever and rapid onset of symptoms may also occur.
- Management: Given the life-threatening nature of Ludwig's angina, immediate medical attention is crucial. A multidisciplinary approach involving dentists, oral and maxillofacial surgeons, and medical professionals is vital for patient care. Treatment typically involves intravenous antibiotics and, in some cases, surgical drainage of the infection. Emphasize the urgency of seeking medical attention to ensure the best possible outcome for patients suffering from Ludwig's angina.

2.3.4.6.4.3.5 Syphilis (oral stage)

- Cause: The bacterium *Treponema pallidum* causes syphilis, which can present in oral lesions during the primary stage of infection [61].

- Symptoms: A painless ulcer or chancre appears in the mouth or lips and may last several weeks if not treated.
- Risk factors: Individuals who engage in unprotected sexual practices are at increased risk of contracting syphilis. Emphasizing the importance of safe sexual practices can help prevent the spread of infection.
- Management: A collaborative approach involving dentists, primary care physicians, and specialists in infectious diseases is essential for proper diagnosis and treatment. Antibiotics, primarily penicillin, are effective in treating syphilis during all stages of infection. Oral syphilis typically resolves with appropriate antimicrobial therapy.

2.3.4.6.4.3.6 Human Papillomavirus (HPV)—oral warts

- Cause: Human papillomavirus (HPV) infections, most associated with HPV types 6 and 11, can lead to the development of warts or papillomas in the oral cavity [62].
- Symptoms: Small, wart-like growths can appear in the mouth, lips, or throat. In some cases, these lesions can be asymptomatic, but they may cause discomfort if located in areas that rub against teeth or dentures.
- Management: While HPV-related oral warts are generally benign, it is important to monitor them for any changes. Treatment may include topical medications, laser ablation, or surgical removal if the lesions become problematic or show signs of malignant transformation. By emphasizing the significance of tracking any changes in the lesions, patients can ensure proper management and appropriate interventions when necessary.

2.3.4.6.4.3.7 Mucosal infections (e.g., recurrent aphthous stomatitis—canker sores)

- Cause: The precise cause of recurrent canker sores (aphthous stomatitis) remains unclear, but they can be triggered by stress, trauma, or nutritional deficiencies. While these lesions are not considered infectious, their recurrent nature can significantly impact oral health [63].
- Symptoms: Painful, round or oval ulcers with a white or yellow center and red borders. They commonly appear inside the mouth, on the cheeks, lips, or tongue.
- Management: A collaborative approach involving both dentists and primary care physicians is crucial for identifying potential triggers and managing symptoms. Common management options include:
    - Topical corticosteroids: These can help reduce inflammation and pain associated with the lesions.
    - Oral antihistamines: These can alleviate discomfort, particularly if an allergic component is suspected.

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- Saltwater rinses: These can promote healing and soothe the affected areas.
- Nutritional support: If nutritional deficiencies are identified, appropriate supplementation may help prevent recurrence.
- Systemic medications: In severe or persistent cases, systemic medications, such as immunomodulators or oral corticosteroids, may be prescribed to manage the condition and prevent flare-ups.

2.3.4.7 Prevention and maintenance of oral health

Preventive care is a cornerstone of maintaining oral health and can help avoid or minimize the severity of various dental diseases. Key components of preventive care include proper oral hygiene, dietary considerations, lifestyle modifications, and professional interventions [64].

2.3.4.7.1 Oral hygiene

Effective oral hygiene practices are essential for controlling plaque accumulation, preventing caries, and maintaining periodontal health. These practices include:

- **Brushing* at least twice daily with fluoride toothpaste, using proper techniques to clean all tooth surfaces and reach difficult-to-access areas.
- **Flossing* daily to remove interproximal plaque and debris.
- **Tongue cleaning*: An essential aspect of maintaining oral hygiene. It aids in reducing the bacteria and debris on the tongue's surface, which can contribute to bad breath, poor taste sensitivity, and an unhealthy oral environment.

There are several tools available for tongue cleaning, and choosing the right one depends on personal preference and effectiveness. Here are a few commonly used tools:

a. Tongue scrapers: These specially designed devices are usually made of plastic, metal, or copper. Tongue scrapers feature a curved or V-shaped edge to gently remove bacteria and debris from the tongue's surface.

b. Toothbrushes: Soft-bristled toothbrushes can be used for tongue cleaning, especially if designed with a tongue cleaner on the back of the brush head. While not as effective as dedicated tongue scrapers, toothbrushes can still significantly reduce bacteria and improve oral hygiene.

  - *Mouthwashes and rinses: Antimicrobial mouthwashes or rinses to reduce plaque and gingivitis: these can help reduce bacteria on the tongue's surface [65]. When used in combination with mechanical cleaning methods, these products can enhance the overall effectiveness of tongue cleaning.

2.3.4.7.1.1 Incorporating powered toothbrushes and water flossers into home care

The integration of advanced tools, such as powered toothbrushes and water flossers, can significantly improve the effectiveness of at-home oral care, especially for those with dexterity challenges or those with orthodontic appliances. Here is a closer look at how these tools can enhance dental hygiene practices:

a. Electric toothbrushes offer several advantages over manual brushing

- Consistent and efficient brushing: Generating thousands of brush strokes per minute, electric toothbrushes provide consistent and efficient cleaning. This leads to better plaque removal and improved gum health [66, 67].
- Timers and pressure sensors: Built-in timers and pressure sensors in powered toothbrushes help ensure users brush for the recommended 2 minutes and apply appropriate pressure, reducing the risk of over-brushing or under-brushing.
- Adaptability: With interchangeable brush heads tailored to specific dental needs, electric toothbrushes are suitable for a range of dental requirements and preferences.

b. Water flossers

- Oral irrigators use a pressurized stream of water or a mixture of water and cleaning solutions to remove plaque, bacteria, and debris from between teeth and below the gumline.
- Effective plaque removal for orthodontic patients: The pressurized water stream easily accesses hard-to-reach areas around braces and other appliances, removing plaque and debris more effectively than string floss [68].
- Ease of use for individuals with dexterity challenges: Water flossers require less manual dexterity than traditional flossing, making them an accessible option for people with limited mobility or hand function [69].
- Enhanced gingival health: By cleaning the sulcus (a small pocket around the tooth), water flossers help reduce gum inflammation and promote gum health.

2.3.4.7.1.1.1 Potential downsides and limitations

While powered toothbrushes and water flossers can significantly enhance oral health, it is essential to consider their potential downsides and limitations. Proper usage is crucial to maximize their effectiveness, and regular dental checkups and professional cleanings should remain a part of overall oral care routines.

a. Powered toothbrushes

While electric toothbrushes offer many advantages [70], consider these potential limitations:

- Cost: Electric toothbrushes can be more expensive than manual toothbrushes, with higher initial costs and additional expenses for replacement brush heads or charging accessories.

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- Dependence on power: Powered toothbrushes require power, which can be inconvenient during travel or if the battery dies unexpectedly.
- Overreliance on technology: Users may become overly reliant on the brushing action of electric toothbrushes, leading to a lack of focus on proper brushing techniques and potentially compromising plaque removal effectiveness.

b. Water flossers

- When incorporating water flossers into a dental care routine [71], consider these factors:
- Cost: Water flossers can be expensive, making them inaccessible to some individuals.
- Dependence on water and energy: They require water and energy, limiting their usability outside the home.
- Affordability and accessibility: These factors should be considered, particularly for those who may not be able to afford or access these tools.
- Storage space: Dedicated storage space is needed for water flossers.

2.3.4.7.2 Dietary considerations

Preventing caries and periodontal diseases significantly relies on a well-balanced diet. Key dietary recommendations include:

2.3.4.7.2.1 Limiting sugary and acidic foods

Excessive consumption of sugary and acidic foods promotes bacterial growth and leads to demineralization of tooth enamel, increasing the risk of dental caries [68]. Examples of such foods include candy, soda, and citrus fruits. It is crucial to reduce the intake of these items to maintain a healthy oral environment.

2.3.4.7.2.2 Consuming a balanced diet rich in essential nutrients

A diet containing adequate amounts of calcium, vitamin D, and phosphorus supports tooth mineralization and strengthens dental hard tissues [72, 73]. Foods like dairy products, leafy greens, and fatty fish are excellent sources of these essential nutrients, helping maintain strong teeth and bones and reducing the risk of dental caries and periodontal diseases.

2.3.4.7.2.3 Including fibrous vegetables and fruits

Foods high in fiber, such as fibrous vegetables and fruits, stimulate saliva production. Saliva is essential for neutralizing acids and protecting teeth from demineralization [68]. Examples include apples, carrots, and celery. These foods also mechanically cleanse the teeth, reducing plaque accumulation and promoting overall oral health [73].

2.3.4.7.3 Lifestyle modifications

Adopting healthy lifestyle habits can significantly reduce the risk of oral diseases. Key lifestyle modifications include:

2.3.4.7.3.1 Avoiding tobacco products and vaping

Both smoking and vaping increase the likelihood of periodontal disease, oral cancer, and other oral health issues [74]. While some people perceive vaping as a safer alternative to smoking, it is essential to recognize that vaping also poses risks to oral health due to the presence of nicotine and other harmful chemicals. Quitting smoking or vaping is crucial for maintaining good oral health. Consult with healthcare professionals for guidance and support in quitting.

2.3.4.7.3.2 Limiting alcohol consumption

Excessive alcohol use can contribute to oral cancer risk and exacerbate periodontal inflammation [74]. Moderation is key; stick to recommended guidelines for alcohol consumption or consider limiting intake altogether.

2.3.4.7.3.3 Managing stress and addressing teeth-grinding habits

High stress levels can lead to teeth grinding (bruxism) and contribute to temporomandibular joint disorders [75]. Incorporate stress-reducing activities into your daily routine, such as meditation, yoga, or regular exercise. If you experience persistent teeth grinding, consult with a dental professional for possible treatment options, such as a custom-fitted mouthguard.

2.3.4.7.3.4 Age-specific preventive care

Oral health needs evolve throughout an individual's lifetime, requiring tailored approaches to address the unique challenges of each age group. By recognizing these distinct needs, dental professionals can implement appropriate interventions and promote optimal oral health at every stage of life.

Children [76]

- Early preventive care is crucial for children, as they are at risk for conditions like early childhood caries.
- Regular dental visits should begin at age one or when the first tooth erupts.
- Parental education on appropriate oral hygiene techniques and dietary habits is essential.
- Application of fluoride varnish or other fluoride treatments can help prevent caries.
- Pit and fissure sealants can protect susceptible teeth from decay.
- Monitoring growth and development can detect malocclusions or other anomalies early on.

Adults [77]

- Tailored management plans should address stress-induced oral problems, such as bruxism and temporomandibular joint disorders.

- Periodontal maintenance therapy is crucial for managing gum disease.

- Restorative treatments can repair damaged or missing teeth.

- Cosmetic treatments like teeth whitening or orthodontic therapy can improve esthetics and function.

- Oral cancer screenings and education on risk factors, such as tobacco use and excessive alcohol consumption, are important for early detection and prevention.

Elderly individuals [78]

- Xerostomia (dry mouth) management is essential, as it increases the risk of caries, fungal infections, and periodontal disease. Strategies include saliva substitutes, fluoride treatments, and adjusting medications when possible.

- Prosthodontic care for dentures and partial dentures is crucial for maintaining oral health and function. Regular checkups, proper denture hygiene, and relining or replacing worn dentures are important aspects of care.

- Interdisciplinary care for systemic diseases and oral health is vital, as conditions like diabetes, cardiovascular disease, and respiratory illnesses can impact oral health and vice versa. Collaborating with medical professionals ensures comprehensive care and improves overall well-being.

2.3.4.7.3.4.1 Professional interventions for maintaining oral health

Regular dental checkups and cleanings are essential for the early detection of oral health issues and the provision of appropriate preventive interventions [79]. Key professional interventions include:

Professional dental cleanings

- Thorough cleaning by dental professionals removes plaque and calculus deposits inaccessible to home care, aiding in the maintenance of periodontal health and reducing caries risk.

Fluoride treatments

- Various forms, such as fluoride varnish, sodium fluoride toothpastes (e.g., Duraphat 0.619 and 1.1%), fluoride mouthwashes, and fluoride mousse (e.g., GC Tooth Mousse), serve to strengthen tooth enamel, enhance remineralization, and reduce sensitivity. These treatments can be particularly beneficial for individuals at increased risk of caries or those experiencing sensitivity.

Dental sealants

- The application of dental sealants to the occlusal surfaces of molars can effectively prevent caries development in susceptible individuals, especially in children and adolescents. This preventive measure is especially important for those who may be at high risk for caries due to their age or other factors.

2.3.4.8 Challenges and solutions

Adopting preventive care strategies is essential for maintaining oral health, but various challenges may arise. Here are some common obstacles and potential solutions:

Busy schedules

- People with hectic routines might struggle to maintain consistent oral hygiene practices. Setting reminders and prioritizing self-care can help overcome this challenge [80].

Cost concerns

- Financial constraints may hinder some individuals from accessing preventive care services, such as regular dental checkups and professional cleanings. Researching dental clinics that offer affordable services, dental insurance options, or government-funded programs can help mitigate these concerns [81].

Dietary habits

- Changing dietary habits to promote oral health can be difficult for some individuals. Making gradual adjustments and focusing on moderation rather than complete elimination can make the transition more manageable [72, 73].

Limited dexterity

- People with dexterity challenges might find traditional oral hygiene practices difficult. Incorporating advanced tools like powered toothbrushes and water flossers can improve at-home oral care effectiveness [82].

Lack of knowledge

- Many people may be unaware of the importance of preventive care and proper oral hygiene practices. Educating individuals on the benefits of maintaining good oral health and providing guidance on proper techniques can empower them to make informed decisions about their dental care [83].

3. Conclusion

This chapter explored the foundations of oral health, emphasizing the importance of understanding the structure, function, and importance of teeth, as well as the supporting tissues. As part of a broader discussion on the intersection of science, disease, and clinical practice, this chapter aimed to contribute to a comprehensive understanding of how oral health impacts overall well-being.

The significance of prevention and early detection was highlighted throughout the chapter, with an emphasis on consistent oral hygiene practices, lifestyle modifications, and regular professional checkups. Early detection, particularly through vigilant clinical and radiographic examinations conducted by dental practitioners, is vital for successful treatment outcomes, especially in cases of oral cancer and other severe conditions affecting oral health.

A range of therapeutic interventions was discussed, focusing on tailoring treatments to the specific needs of individuals across all life stages. These interventions span restorative procedures, pharmacological therapies for infections and inflammatory conditions, and invasive options such as surgical interventions and oncologic treatments. The focus remained on addressing oral health in the context of disease and clinical practice.

Innovative technologies, like powered toothbrushes and water flossers, were showcased for their contributions to improving daily oral hygiene and maintaining oral health. These tools, combined with personalized care approaches and interdisciplinary strategies, play a pivotal role in reinforcing the connection between oral health and overall systemic health.

By fostering awareness of oral health's foundations and the interconnectedness of science, disease, and clinical practice, dental professionals and individuals alike can collaborate to achieve better oral health outcomes, enhance overall quality of life, and promote the early detection of oral diseases across the lifespan. Understanding and caring for oral health are essential aspects of the pursuit of optimal health and well-being.

Conflict of interest

The authors declare no conflict of interest.

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Chapter 4

Dental Procedures in Patients with Increased Risk of Bleeding Due to Antithrombotic Medications

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Abstract

Patients who are on anticoagulant or antiaggregant therapy are not only at risk of prolonged bleeding after minor surgical interventions, but are also at risk of worsening the condition of the underlying disease due to the preoperative discontinuation of anticoagulant or antiplatelet therapy. In outpatient surgery, the conditions for monitoring patients who are at high risk of bleeding are not satisfactory. Today, there are new kinds of anticoagulants that exert their effect in different ways and different times. Taking into account that a certain number of patients use dual and even triple anticoagulant therapy, preoperative and postoperative protocols for the care of such patients should be clearly defined.

Keywords: oral treatment, hemorrhage, anticoagulant drugs, antiaggregant drug, thromboembolic events

1. Introduction

In daily clinical practice, there are patients who are exposed to certain risk of periodontal, conservative dental procedures or oral surgical interventions. A significant proportion of these patients suffer from cardiovascular and neurological diseases, as well as potential venous thromboembolism. Thrombosis occurs due to the interaction between a damaged blood vessel wall and platelets. During platelet activation, the coagulation cascade is also triggered through the release of tissue factor, leading to fibrin formation.

The COVID-19 pandemic was associated with a higher incidence of thromboembolic complications, often resulting in severe outcomes. Consequently, the number of patients receiving antithrombotic therapy has significantly increased. These patients have received some of chronic oral antithrombotic medications, whose interruption can cause severe consequences but continuations can be related to perioperative heavy bleeding. The clearly defined protocols for each type of therapy are not harmonized, so dealing with such patients in ambulatory surgery is almost always a challenge.

2. Types of antithrombotic therapy

Antithrombotic therapy includes:

- *Antiplatelet therapy* – Reduces platelet activation and aggregation.
- *Anticoagulant therapy* – Inhibits the coagulation cascade.
- *Fibrinolytic therapy* – Breaks down existing clots.

In ambulatory oral surgery, we often treat patients who are on oral antiplatelet or oral anticoagulant therapy, or in some cases, both simultaneously.

2.1 Antiplatelet therapy

Antiplatelet medications work by modifying platelet function, primarily by inhibiting aggregation, adhesion, or activation of the platelets. They reduce platelet response to vascular injury, limiting thrombus formation and decreasing the release of vasoactive substances from platelets. This therapy specifically targets the second phase of hemostasis (platelet aggregation) and prevents intravascular clot development.

Types of antiplatelet medications [1].

- *Arachidonic acid metabolism inhibitors* – e.g., Aspirin (acetylsalicylic acid)
- *P2Y12 receptor inhibitors* – e.g., Clopidogrel, Prasugrel, Ticagrelor (oral), and Cangrelor (parenteral)
- *GPIIb/IIIa receptor inhibitors* – e.g., Eptifibatide and Tirofiban (parenteral), used for acute coronary syndrome

Aspirin has a wide range of pharmacological effects depending on the dosage: at 0.5–1 mg/kg, it inhibits platelet aggregation; whereas at 5 mg/kg, it exerts analgesic and antipyretic, as well as anti-inflammatory properties.

The antiplatelet effect of aspirin begins 48 hours after administration and is associated with a prolonged bleeding time of up to 2 hours. Its antithrombotic action results from the irreversible inhibition of cyclooxygenase (COX) activity in platelets. Cyclooxygenase catalyzes the conversion of arachidonic acid into thromboxane A2, a key promoter of platelet degranulation and aggregation. Arachidonic acid is released from the cell membrane by the action of phospholipase-A2. Aspirin permanently inhibits both cyclooxygenase 1 (COX-1) and cyclooxygenase 2 (COX-2) enzymes, thereby reducing thromboxane A2 levels [2].

Since platelets do not possess nucleus and have a lifespan of 7–10 days, they cannot resynthesize thromboxane A2. Approximately 10% of platelets are replaced daily, which is why oral antiplatelet therapy (OAT) is administered chronically, on a daily basis. Despite its elimination half-life of about 4 hours, aspirin's effect is independent of its clearance, as its action relies on the irreversible inhibition of cyclooxygenase. Long-term administration of high-dose aspirin (above 500 mg/day) also reduces thrombin synthesis [3].

Bleeding time remains prolonged until the platelet population is replenished, which takes approximately 7–10 days. Therefore, aspirin should be discontinued 5–7 days before surgical procedures to be sure about perioperative bleeding management. Any adjustment to the medication regimen before dental surgery should only be made after consulting with and following the advice of the patient's physician.

Platelets interact with leukocytes and endothelial cells during periods of stress and inflammation [4]. Aspirin inhibits the release of prostaglandin E2, a key inflammatory and pain-modulating substance. Prostaglandins contribute to hyperexcitability of peripheral nerve endings in inflamed tissues and facilitate pain signal transmission to the central nervous system. By blocking cyclooxygenase, aspirin disrupts prostaglandin synthesis, effectively reducing inflammation and pain.

Clopidogrel is a member of the thienopyridine class. These agents exert their antiplatelet effect by inhibiting the platelet adenosine diphosphate (ADP) receptor—specifically, the $P2Y_{12}$ receptor—thus preventing platelet activation and aggregation. Clopidogrel also exerts pleiotropic effects like anti-inflammatory, anticancer, and bone homeostasis-modulating effects. Also, this medication possesses many non-$P2Y_{12}$ receptor-dependent effects like: the regulation of hematopoiesis, inhibition of vascular remodeling, increased coronary perfusion, modulation of vascular function, and adverse bleeding [5].

Clopidogrel reaches its full therapeutic antiplatelet effect within 4–5 hours of administration. As it acts on platelets over their 7–10-day lifespan, normal platelet function is only restored as new platelets are produced, typically returning to full functionality within 7–10 days. Therefore, clopidogrel should be discontinued 5–7 days before surgery to allow for adequate recovery of platelet function [6].

During antiplatelet therapy, an increased bleeding tendency is expected. However, discontinuing such therapy raises the risk of complications related to the underlying disease, as well as the potential for severe thromboembolic events. Thus, the decision to interrupt antiplatelet treatment involves balancing the risk of thromboembolism against the likelihood of bleeding. Notably, cessation of therapy has been associated with excessive thromboxane A2 activity and diminished fibrinolytic function (**Table 1**) [7].

Property	Aspirin	Clopidogrel
Drug class	Nonsteroidal anti-inflammatory drug (NSAID)	Thienopyridine
Mechanism of action	Irreversible *COX-1 & COX-2 inhibition*, reducing thromboxane A2 and platelet aggregation	Irreversible *P2Y12 (ADP receptor) blockade*, preventing platelet activation and aggregation
Onset of full effect	*48 hours* after administration	*4–5 hours* after administration
Duration of action	Until new platelets are produced (*7–10 days*)	Until new platelets are produced (*7–10 days*)
Pre-surgical considerations	Cessation is not recommended	Cessation is not recommended
Pre-surgical cessation necessary	5–7 days before surgery	Stop 7 days before surgery

Table 1.
Comparison of aspirin and clopidogrel.

2.2 Discontinuation of antiplatelet therapy and risk of thromboembolic complications

Interrupting antiplatelet and anticoagulant therapy can lead to serious and potentially fatal thromboembolic events. According to the literature, therapy discontinuation may result in acute myocardial infarction, stroke, or stent thrombosis, highlighting the importance of continuous therapy for high-risk patients.

Mehra et al. analyzed the management of patients at high risk of thromboembolism undergoing dental and oral surgical procedures. They emphasized that discontinuation of antithrombotic therapy in chronically anticoagulated patients is associated with an increased risk of thromboembolic complications [8]. Some studies indicate that cessation of aspirin therapy may trigger a rebound phenomenon, wherein heightened platelet reactivity leads to a prothrombotic state that can precipitate thromboembolic events [9].

Interrupting antiplatelet therapy can have very serious consequences. In patients with coronary stents, thromboembolism occurs in approximately 20–40% of cases during the perioperative drug cessation period, carrying a high risk of both mortality and morbidity. For example, an analysis of 36 cases of late thrombosis in drug-eluting stents demonstrated significant adverse outcomes [10]. Collet et al. reported that among 475 patients hospitalized due to acute myocardial infarction, discontinuation of antiplatelet therapy caused 20 events—with cessation period from 3 to 15 days prior to surgery [11].

Given the severity of these consequences, current clinical guidelines strongly recommend continuing antiplatelet therapy during the perioperative period, except in cases where temporary discontinuation is absolutely necessary, like in huge maxillofacial interventions. In such situations, therapy discontinuation should be limited to the shortest possible duration, carefully weighing the risk of thromboembolism against the risk of bleeding.

2.3 Postoperative bleeding and perioperative management in patients on single dual antiplatelet therapy

Dual antiplatelet therapy (DAPT), which includes a combination of acetylsalicylic acid (aspirin) and a P2Y12 glycoprotein receptor inhibitor (such as ticagrelor, prasugrel, or clopidogrel), is used preventively in patients with acute coronary syndrome (ACS) and those who have undergone coronary stent implantation. The standard recommendation is to continue this therapy for at least 12 months after stent placement to reduce the risk of thromboembolic complications and maintain adequate blood vessel patency. Dual antiplatelet therapy increases the risk of intracerebral hemorrhage by 42% [12].

Bajkin et al. reported a 1.7% incidence of post-extraction hemorrhage in patients receiving dual antiplatelet therapy (DAPT) [13]. Doganay et al. observed a 1.8% rate of postoperative bleeding in patients on ticagrelor, aspirin, clopidogrel, and dual antiplatelet therapy after tooth extraction and minor oral surgery [14]. According to these data, discontinuation of dual antiplatelet therapy is not necessary.

Discontinuing DAPT in such patients increases the risk of thromboembolism significantly, with some data suggesting a threefold increase in risk for those with coronary stents [15]. Disruption of antiplatelet therapy leads to increased thromboxane A2 activity and decreased fibrinolytic activity, creating a prothrombotic condition that may lead to thromboembolism. Studies also suggest that there could be a rebound platelet phenomenon following aspirin discontinuation, which further increases the risk of thrombotic events [14, 16–18].

In patients with coronary stents, it is recommended to postpone elective dental procedures that may be associated with bleeding.

Current guidelines advise continuing antiplatelet therapy during the perioperative period, whenever possible [19]. Long-term discontinuation is not supported by clinical evidence, particularly because bleeding complications in these patients can usually be managed with local hemostatic measures, even in ambulatory dental procedures [20, 21].

If it is necessary to discontinue antiplatelet therapy, it should be limited to 3 days or less. The risk of thromboembolic events increases considerably if the therapy is stopped for 4 days or more [9]. The second option is bridging perioperative period with exclusion antiplatelet therapy and inclusion of low-molecular-weight heparin (LMWH) in therapy.

2.4 Dental management and antiplatelet therapy

The risk of bleeding decreases with meticulously planned surgical protocol and multifactorial manner of local hemostasis.

Dental extraction or other oral surgical interventions are the most frequently reported interventions with a risk of postoperative bleeding. However, periodontal procedures, with a large surface area without the possibility of suturing or placing hemostatic agents in the operating field, appear to be the greatest cause of bleeding. Nonsurgical periodontal treatment [22], ultrasonic scaling, gingivectomy, even probing and pre-prosthetic preparation [23], are reported procedures with risk of perioperative bleeding in antiplatelet drug consumers. Local risk factor (periodontitis) leads to hyperemia, which adds to increased incidence of bleeding on probing in these patients.

Based on the Scottish Dental Clinical Effectiveness Programme, and other recommendations, dental procedures are classified by their bleeding risk during the perioperative period [24–26].

2.4.1 Low-risk dental procedures

- Extraction of up to three teeth
- Surgical removal of a single tooth
- Performing incisional biopsies
- Excision of small, localized mucosal lesions
- Incision and drainage of intraoral abscesses
- Subgingival curettage
- Placement of up to three implants in one session

It is important to consider whether the teeth are multi-rooted or single-rooted, as well as the size of the extraction socket. The protocol should be primarily adjusted to the dimensions of the bony and soft tissue defect that needs to be filled with a healthy clot. Extraction of multi-rooted teeth increases the risk of bleeding.

2.4.2 High-risk dental procedures

- Extraction of three or more teeth
- Surgery for cysts or tumors
- Periodontal surgery
- Preprosthetic surgical procedures
- Placement of three or more implants in one visit
- Periradicular surgery
- Oral surgeries that last longer than 45 minutes

2.4.3 Hemostatic measures

- Fill the extraction socket with hemostatic agents based on collagen, gelatin, or fibrin.
- Suture the wound.
- Topically apply an antifibrinolytic agent 3–4 times daily.
- Apply a cold compress externally to the surgical area.
- Advise the patient to avoid rinsing or applying medications directly to the wound.
- Recommend that the patient avoid using nonsteroidal anti-inflammatory drugs (NSAIDs), such as ibuprofen, diclofenac, or other salicylate-containing drugs, when possible.

Commonly employed local agents for controlling bleeding include oxidized cellulose, absorbable gelatin or collagen sponges, fibrin glue, cyanoacrylate adhesive, platelet-rich plasma gel, and antifibrinolytic agents—which can be applied directly to the wound or used as a mouthwash solution [27]. None of the local hemostatic agents has been shown to be superior to the others [16].

Even if bleeding occurs, it is generally manageable with conservative hemostatic measures, such as: Readmission and observation of patients, repeated suturing of mucosa, application of local tranexamic acid or surgicel, or compression of the wound. If the principles of hemostasis are respected, bleeding episodes should not be expected, although for sure never could be totally avoided [17].

2.5 Anticoagulant therapy

Anticoagulant agents are divided into:

- *Oral anticoagulants*—Vitamin K antagonists (Warfarin, Acenocoumarol, Phenprocoumon) and direct oral anticoagulants (Dabigatran, Ribaroxaban, Apixaban, Edoxaban)

- *Parenteral anticoagulants* (direct FII or factor Xa (FXa) inhibitors)—low molecular heparin, bivalirudin, and fondaparinux

Oral vitamin K antagonists inhibit the enzyme vitamin K epoxide reductase and prevent the conversion of vitamin K epoxide into the active form necessary for the synthesis of prothrombin in the liver. In this manner, vitamin K antagonists inhibit synthesis of vitamin K-dependent coagulation factors in liver [28].

Vitamin K antagonist works by competitively inhibiting the liver's synthesis of all vitamin K-dependent clotting factors (II, VII, IX, and X), reducing their production by roughly 30 to 50%. Because it does not affect clotting factors already circulating in the blood, there is a delay before its full effect is seen. Although peak plasma levels occur within 1 hour of administration, the complete pharmacological effect of warfarin typically takes 48 hours to manifest. In fact, the impact of a single dose begins within 12–16 hours, with maximum effects observed between 48 and 72 hours, and the overall effect lasts for 4–5 days. Furthermore, it may take up to 10–14 days for the dose to stabilize.

2.6 Vitamin K antagonists and interactions with food and drugs

Vitamin K antagonists are known to interact with more than 500 substances found in both food and medications, which can amplify their anticoagulant effects [29]. Common interacting substances include cardiovascular medications (such as fluvastatin, lovastatin, rosuvastatin, and simvastatin), which may interact with warfarin [30, 31], antibiotics (such as metronidazole, erythromycin) [32], steroids [33], various herbal products, alcohol, grapefruit juice, parsley, and spicy foods. These interactions may lead to serious side effects, such as life-threatening bleeding from any tissue or organ, as well as vasculitis, hepatitis, increased liver enzymes, and gastrointestinal symptoms like nausea, vomiting, diarrhea, abdominal pain, and flatulence. Skin reactions such as rash and dermatitis may also occur. One of the most significant adverse effects of warfarin is skin necrosis. Although rare, this complication generally appears between the third and eighth day of treatment and is caused by widespread clotting in the small venules and capillaries of the subcutaneous fat [34].

2.7 Vitamin K antagonists' coagulation assessment before oral surgery

The appropriate therapeutic dose of vitamin K antagonists is determined by the International Normalized Ratio (INR), a standardized measure of prothrombin time that remains consistent across different testing methods. Generally, the target INR is set at about 2.5 times the normal value (1.0), with a typical range of 2.5–3.5; for patients with artificial heart valves, the recommended range is higher, around 3.5–4. It is also crucial that the INR measurement used for dose adjustments is no more than 24 hours old.

Routine coagulation testing is necessary before bloody interventions, which should be safely performed when INR is in the therapeutic range of 2–3, even according to Scottish Dental Clinical Effectiveness Programme and other data [24, 35]. If bleeding persists for over 4 hours, the patient should be referred to a transfusion specialist for further evaluation, including a repeat INR test, to determine the underlying cause.

2.8 Perioperative management in patients on vitamin K antagonist therapy

The management of vitamin K antagonists before oral surgery includes several approaches: discontinuation for a few days, temporary bridging with heparin, dose reduction without bridging, or maintaining the usual dosage while controlling bleeding with local hemostatic measures. Heparin is advantageous due to its short half-life, allowing for better control. Switching to heparin as a bridge therapy elevates the bleeding risk compared to continuing vitamin K antagonist treatment without interruption [36]. Extended use of heparin can be troublesome and has been linked to the development of osteoporosis [28]. Regardless of the chosen approach, preoperative coagulation testing is crucial to assess the patient's anticoagulation status [36].

In consultation with the patient's physician, one might consider delaying the daily anticoagulant dose until after the procedure, scheduling the dental treatment as late as possible following the last dose, or temporarily halting the medication for 24–48 hours, but it is generally not recommended. When warfarin is stopped, its anticoagulant effect diminishes gradually. For instance, an INR maintained between 2.0 and 3.0 will typically return to the normal range within 4–5 days [37]. Oral anticoagulant therapy (OAT) with warfarin should not be stopped by the oral surgeon before or after surgery. The primary physician who prescribed the warfarin should decide on its cessation, based on a careful evaluation of risks and benefits for each case.

Among patients on vitamin K antagonists, the bleeding rate following low-risk procedures remains similar whether or not warfarin is discontinued [38–40]. Current guidelines suggest that for minor oral surgical procedures, patients should continue their antagonist vitamin K therapy throughout the perioperative period. Conversely, for major oral and maxillofacial surgeries, it is acceptable to temporarily substitute the oral anticoagulant with a parenteral alternative. Boulin et al. [41] concluded that using bridging therapy is linked to an increased risk of bleeding, while the risk of arterial thromboembolism remains similar to cases where no bridging is used.

The 5th day **before the intervention**	*Warfarin* - **exclude from therapy**
The 3th day before the intervention	*LMWH* - the first preoperative dose
12 hours before the intervention	*LMWH* - the last preoperative dose
12 hours after the intervention	*LMWH* - the first postoperative dose
The 1st postoperative day	*Warfarin* - introduce along with LMWH
The next 3 postoperative days	*Warfarin* and LMWH - overlap
The 4th postoperative day	*INR* value - control
The 4^t *INR > 2* *INR > 2.5 - for artificial valves*	*LMWH* - exclude *Warfarin* - continue
The 4^t *INR < 2* *INR < 2.5 - for artificial valves*	*Warfarin and LMWH* overlap to the target *INR* value

Table 2.
The bridging protocol for vitamin K antagonists to LMWH.

The bridging protocol for vitamin K antagonists to LMWH (**Table 2**) typically spans about 5 days and is particularly crucial for patients who are at the highest risk of thromboembolic events. Due to drawbacks like a slow onset of action, the need for frequent INR monitoring, numerous drug and food interactions, and the requirement for precise dose adjustments, vitamin K antagonists are increasingly being replaced by newer direct oral anticoagulants. However, VKAs remain essential for certain patient groups, such as those patients with artificial mechanical valves, subacute bacterial endocarditis, moderate to severe mitral stenosis, and significantly reduced glomerular filtration.

2.9 Direct oral anticoagulants (DOACs)

DOACs represent a new generation of anticoagulants that directly inhibit specific coagulation factors. They are classified into:

- Direct thrombin (Factor IIa) inhibitors
- Factor Xa (FXa) inhibitors

The common feature for DOAC is exerting very fast pharmacological effects, hepatic metabolism, renal exertion, not individual but general dosage. Routine timely ordered testing is not necessary, due to rapid transient effects on coagulation status in case of cessation of dosage. Their effects not only become clinically apparent in 2–4 hours, but are also clinically transient in a day [42].

2.9.1 Direct thrombin inhibitor (FIIa): Dabigatran (Pradaxa®)

Dabigatran is a direct thrombin inhibitor that neutralizes thrombin within blood clots, thereby reducing fibrin production and preventing thrombin-induced platelet activation. Its plasma concentration reaches its peak approximately 2–3 hours after administration, with a recommended dosing schedule of twice daily (morning and evening). Since dabigatran is predominantly excreted through the kidneys, renal function plays a crucial role in determining its suitability for use.

In healthy individuals, the drug's elimination half-life ranges between 12 and 17 hours, whereas in patients with renal impairment, it can exceed 28 hours. Regular monitoring of kidney function is essential, particularly in elderly individuals, with assessments recommended every 2 years to ensure that dabigatran excretion remains unimpaired. The Cockcroft-Gault formula is a useful tool for estimating creatinine clearance, which helps in deciding whether dabigatran is appropriate for a particular patient.

2.9.2 Factor Xa (FXa) inhibitors

These drugs bind directly to activated Factor Xa, which is a crucial enzyme (protease) in the coagulation cascade, responsible for converting prothrombin (Factor II) into thrombin with definitely clot formation. The pivotal role of FXa is linking both the intrinsic and extrinsic pathways of blood clotting, in coagulation cascade. There are three FXa inhibitors that are Food and Drug Administration (FDA) approved:

Drug	Class	Peak conc.	Dosage	Half-life	Excretion	Precaution
Dabigatran (Pradaxa®)	Direct thrombin (FIIa) inhibitor	2–3 h	Twice daily (morning & evening)	12–17 h (28 h in renal impairment)	80% renal, 20% liver	Renal function monitoring needed
Rivaroxaban (Xarelto®)	FXa inhibitor	2.5–4 h	Once daily (morning)	5–9 h (12–13 h in elderly)	65% liver, 35% renal	Liver disease increases bleeding risk
Apixaban (Eliquis®)	FXa inhibitor	1–3 h	Twice daily (every 12 h)	8–15 h (~12 h avg.)	27% renal, 73% liver	Caution in elderly & liver disease
Edoxaban (Lixiana®)	FXa inhibitor	2–4 h	Once daily (evening)	10–14 h	50% renal, 50% liver	Use with caution in kidney/liver disease

Table 3.
The properties of direct oral anticoagulants (DOACs).

Rivaroxaban (Xarelto®) Peak plasma concentration: 2.5–4 hours, with dosage once daily, in the morning. Elimination half-life: 5–9 hours in younger patients and 12–13 hours in patients over 75 years. It is 65% degraded in the liver, 35% excreted unchanged by the kidneys.

Apixaban (Eliquis®) Peak plasma concentration: 1–3 hours, with dosage twice daily (every 12 hours). Elimination half-life: 8–15 hours (~12 hours on average); with 73% hepatic metabolism and 27% renal, so precaution is needed in elderly patients and those with liver disease. Apixaban can be used in patients with renal impairment, due to its predominantly hepatic metabolism. It is important to recognize the progressive decline in liver function with advancing age. In individuals over the age of 65, liver function is typically reduced to approximately 65% of the capacity observed in the same individuals during their younger years.

Edoxaban (Lixiana®) Peak plasma concentration: 2–4 hours with dosage once daily, in the evening. Elimination half-life: 10–14 hours thanks to hepatic metabolism 50% and renal excretion l renal 50%, so it must be used with caution in elderly patients and those with moderate liver or kidney impairment (**Table 3**).

2.10 DOACs and interactions with food and drugs

Direct oral anticoagulants (DOACs) generally have minimal interactions with food and other medications, but certain interactions should be noted.

DOACs serve as substrates for the P-glycoprotein (P-gp) transporter, a transmembrane efflux pump, meaning they can interact with other medications that utilize P-gp. P-gp inducers (e.g., dexamethasone, carbamazepine, phenytoin, phenobarbital, St. John's wort) enhance the activity of this transporter, accelerating DOAC elimination and decreasing its concentration in the bloodstream—potentially reducing anticoagulant effectiveness by approximately 50% [29].

Drug-related factors	Patient-related factors
Pharmacological parameters of the drug	Age
Dose (Pradaxa 110 or 150) (Warfarin –individually)	Liver function
Dosing frequency (once or twice daily)	Kidney function
Duration of action	Presence of comorbidities
Interactions	Cooperation of patient

Table 4.
Coagulation status and related factors.

P-gp inhibitors (e.g., verapamil, cyclosporine, amiodarone, quinidine, azithromycin, clarithromycin, erythromycin, ketoconazole) block this transporter, increasing drug concentration and elevating the risk of adverse effects, particularly bleeding. Amiodarone, ketoconazole, and quinidine can raise dabigatran levels by over 100% [43, 44].

NSAIDs (aspirin, ibuprofen, diclofenac) can elevate the risk of bleeding by further impairing platelet function and affecting the gastrointestinal lining. This caution also refers to vitamin K antagonists.

2.11 DOACs' coagulation assessment before oral surgery

Standard coagulation tests (PTa, TT, aPTT) can provide insight into the presence of anticoagulants, even though they are not always sufficient for accurate quantification. Specialized assays, such as the modified anti-Xa test for apixaban and rivaroxaban or the Hemoclot® test for dabigatran, are recommended [45].

Modified Anti-Xa Test – A specific assay is used to determine the concentration of apixaban and rivaroxaban. Standard PT and aPTT tests are not reliable for measuring these drugs.

Hemoclot® Test (Diluted Thrombin Time) – The most precise test for measuring dabigatran levels in the blood.

PTa (Prothrombin Time Adjusted for Anti-Xa Inhibitors) – This test assesses the effects of anticoagulants that inhibit factor Xa, such as apixaban and rivaroxaban. However, a normal result does not rule out the presence of therapeutic levels of apixaban.

TT (Thrombin Time) – A highly sensitive test for detecting dabigatran, a direct thrombin inhibitor. If prolonged, it indicates the presence of the drug.

aPTT (Activated Partial Thromboplastin Time) – May be prolonged in patients taking dabigatran, but it is not a reliable method for precise quantification [45]. At peak plasma concentrations, these values are typically doubled compared to normal levels (**Table 4**).

2.12 Perioperative management for patients on DOACs

The management of DOACs before oral surgery includes several approaches: discontinuation in certain circumstances, temporary bridging with heparin or maintaining the usual dosage while controlling bleeding with local hemostatic measures.

Regardless of the chosen approach, preoperative coagulation testing is not necessary in patients with normal renal function.

Routine coagulation testing is not necessary before conservative, oral surgery or periodontal procedures in patients taking DOACs. Instead, coagulation status can be indirectly assessed by the pharmacological properties of the DOAC, the patient's overall health, and the patient's age.

2.13 Bleeding risk comparison in vitamin k antagonists and DOACs

The bleeding risk associated with DOACs is comparable to that of vitamin K antagonists when INR is maintained within the 2–4 range [46, 47].

2.14 The bridging protocol for DOACs

Bridging should only be applied in patients at the highest risk of thromboembolic complications [48]. Overlap with parenteral anticoagulants should occur at the time when the next DOAC dose is scheduled (12–24 hours after the last dose). Initiate DOAC therapy 0–2 hours before the next scheduled dose of the parenteral anticoagulant.

2.15 Minor oral surgical procedures in DOAC patients

DOAC therapy should generally not be interrupted for low-risk interventions, including:

- Extraction of up to three teeth
- Surgical removal of a single tooth
- Incisional biopsies
- Excision of localized mucosal lesions
- Incision and drainage of intraoral abscesses
- Subgingival curettage
- Placement of up to three implants in one session

2.15.1 Timing considerations

- The ideal timing for surgery is at least *4 hours after the last DOAC dose* [49].
- The peak bleeding risk occurs *2–4 hours post-dose* (**Table 5**).

DOAC	Dosing interval	Recommended surgery timing
Dabigatran (Pradaxa)	12 hours	6 hours after the last dose
Apixaban (Eliquis)	12 hours	6 hours after the last dose
Rivaroxaban(Xarelto)	24 hours	Later in the day
Edoxaban (Lixiana)	24 hours	Early in the morning

Table 5.
Recommended surgery timing for DOAC users.

2.16 High-risk surgical procedures in DOAC patients

For more invasive procedures, temporary discontinuation of DOAC therapy is advised [24]:

- Extraction of three or more teeth
- Cyst or tumor surgery
- Periodontal surgery
- Preprosthetic surgical procedures
- Placement of three or more implants in one visit
- Periradicular surgery
- Oral surgeries lasting over 45 minutes

The first dose of DOACs after surgery should be administered at least 4 hours postoperatively.

For patients on direct oral anticoagulants (DOACs), the recommended dosing adjustments before and after an intervention are as follows [48]:

Dabigatran and apixaban, which are taken twice daily, require skipping the morning dose on the day of the intervention. The first dose after the procedure should be taken at the usual evening time.

Rivaroxaban, taken once daily in the morning, should be postponed before the intervention. The first post-procedure dose should be taken 4 hours after hemostasis is well established. Edoxaban, taken once daily in the evening, does not require dose adjustments before the procedure. The first post-procedure dose should be taken at the usual evening time.

For patients with renal impairment, the last DOAC dose should be taken 2–3 elimination half-lives before surgery.

2.17 Comparing vitamin K antagonists (VKAs) and DOACs

- VKAs (e.g., warfarin) take 48–96 hours to reach peak effect, with a half-life of 20–60 hours.
- DOACs reach peak levels within 2–4 hours, with a half-life of 5–17 hours.

Procedure type	DOAC management
Minor oral surgery (e.g., extraction of ≤3 teeth, simple biopsies, single implant)	No need to interrupt DOAC therapy (conditional recommendation)
Major oral surgery (e.g., extraction of multiple teeth, cyst/tumor surgery, periodontal surgery, multiple implants)	DOAC therapy should be temporarily discontinued
Ideal timing for surgery	At least 4 hours after last DOAC dose
Peak bleeding risk	2–4 hours after last dose of DOAC

Table 6.
Simplified guidelines for oral surgery in patients on DOACs.

Characteristic	**Indirect oral anticoagulants (Warfarin, Dicoumarol derivatives)**	**Direct oral anticoagulants (DOACs/NOACs: Dabigatran, Rivaroxaban, Apixaban, Edoxaban)**
Mechanism of action	Inhibits vitamin K-dependent clotting factors (II, VII, IX, X)	Directly inhibits specific coagulation factors (thrombin [FIIa] or factor Xa)
Onset of action	Slow (12–16 hours)	Rapid (1–2 hours)
Peak effect	48–96 hours	2–4 hours
Monitoring requirement	INR (frequent testing required)	No routine monitoring required
Half-life	Long (20–60 hours)	Shorter (5–17 hours, varies by drug)
Drug-food interactions	High (affected by vitamin K intake, grapefruit, alcohol, etc.)	Minimal
Drug-drug interactions	High (interacts with >200 drugs, including antibiotics, NSAIDs)	Moderate (P-gp and CYP3A4 interactions)
Dosing frequency	Once daily	Once or twice daily, depending on the drug
Reversibility	Vitamin K, fresh frozen plasma, PCC (slow reversal)	Specific reversal agents available (idarucizumab for dabigatran; andexanet alfa for FXa inhibitors)
Use in renal impairment	Preferred in severe renal dysfunction	Requires dose adjustment or avoidance in severe renal impairment
Use in mechanical heart valves	First-line therapy	Not recommended
Risk of postoperative bleeding	Higher, but can be managed with monitoring	Lower, but difficult to assess due to lack of routine testing
Management of missed dose	Less critical due to long half-life	More critical due to shorter half-life and faster action

Table 7.
Comparison table between indirect (old) oral anticoagulants and direct (new) oral anticoagulants (DOACs/NOACs).

This difference means that VKA users have a lower thromboembolic risk if they miss a single dose compared to DOAC users. However, in the case of postoperative bleeding, DOAC therapy can be paused, allowing for quicker resolution due to its shorter half-life.

Upon resumption, DOAC users return to an anticoagulated state within 2–4 hours, reducing the thromboembolic risk. Consequently, DOAC dose management is generally easier for dentists compared to warfarin.

Studies suggest a lower postoperative bleeding risk in DOAC users compared to VKA users [50].

2.17.1 Recommendations for clinical practice

1. Schedule procedures earlier in the day and week to allow time for potential management of prolonged bleeding or rebleeding [24].

2. For patients on short-term high-dose DOAC therapy, delay invasive procedures until switching to standard doses.

3. If DOAC administration is limited in time, postpone elective invasive procedures until the therapy is completed.

4. Assess coagulation status indirectly based on drug pharmacokinetics, patient age, and overall health.

5. DOACs should not be discontinued without prior consultation with the prescribing physician (**Tables 6** and 7).

3. Conclusion

Effective perioperative management of anticoagulated patients requires well-coordinated interdisciplinary collaboration to reduce and prevent both postoperative bleeding and thromboembolic events.

The primary determinants of postoperative bleeding risk include the volume of the post-extraction wound, the duration of the oral procedure, and comorbidities.

In most cases, discontinuing antithrombotic therapy is unnecessary. The introduction of DOACs has improved perioperative bleeding management and minimized the need for major adjustments in the treatment regimen for patients on anticoagulant therapy.

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Section 2

Developmental Dentistry

Chapter 5

Orthodontics and Craniofacial Anomalies

Alicja Zawiślak

Abstract

Orthodontics plays a crucial role in the treatment of craniofacial anomalies, which include a range of congenital and acquired conditions affecting the skull and facial structures. These anomalies, such as malocclusions, cleft lip and palate, and craniofacial growth disorders, can significantly impact both functional and esthetic aspects of a patient's life. The management of these conditions requires a multidisciplinary approach, combining orthodontic treatments with surgical interventions and growth modulation techniques. Key orthodontic strategies include the use of appliance therapy, functional appliances, and the integration of orthognathic surgery to address dental misalignments, skeletal discrepancies, and support for cleft lip and palate repair. Advances in modern diagnostics, genetic research, and artificial intelligence are transforming treatment planning and improving precision in care. Additionally, understanding craniofacial growth patterns is essential for determining the appropriate timing of interventions, which can have a long-lasting impact on patient outcomes. This chapter explores the vital role of orthodontics in the management of craniofacial anomalies, highlighting the importance of a comprehensive, evidence-based approach that combines current technologies with a deep understanding of craniofacial development to enhance both functional and esthetic results for patients.

Keywords: malocclusion, cleft lip, cleft palate, craniofacial growth, craniofacial development

1. Introduction

Orthodontics plays a pivotal role in addressing craniofacial anomalies—congenital or acquired conditions affecting the structure and function of the face. These include malocclusions, cleft lip and palate, and craniofacial growth disorders, which can impair speech, chewing, and esthetics, influencing both physical and psychosocial well-being. Orofacial clefts (OFC), among the most common birth defects, occur in approximately 1 in 700 newborns [1].

Orofacial clefts (OFC) are among the most frequently occurring congenital birth defects, impacting the structure and functionality of the lip and palate, with an incidence rate of approximately 1 in every 700 newborns. Effective management of these conditions relies on a multidisciplinary approach, with orthodontics contributing significantly to restoring dental alignment, occlusion, and maxillary shape. Collaboration with maxillofacial surgeons, speech therapists, pediatricians, and geneticists ensures comprehensive, individualized treatment that improves both function and quality of life [1, 2].

Technological advancements, alongside a deeper understanding of craniofacial growth and development, have further transformed care. Tools like 3D imaging, cone-beam computed tomography (CBCT), and digital modeling allow for precise diagnostics and tailored treatment planning [3].

Innovations such as 3D-printed appliances and clear aligners enhance comfort, reduce treatment time, and improve outcomes [3, 4].

Treatment must also address the emotional impact of craniofacial anomalies, particularly during developmental years. A holistic, patient-centered approach that integrates cutting-edge technology and early intervention strategies is key to long-term success [3, 5].

Looking forward, developments in genetics artificial intelligence (AI) and minimally invasive techniques promise even more precise, efficient, and personalized care. As understanding of craniofacial growth deepens, orthodontics remains central in evolving multidisciplinary strategies to improve the lives of affected individuals [1, 3, 4, 6].

2. Pathophysiology of craniofacial anomalies

In this section, we will discuss the pathophysiology of craniofacial anomalies, exploring the complex mechanisms that lead to abnormal development or growth of the skull and face. The section will cover genetic factors, including mutations in specific genes that affect craniofacial development, as well as the role of environmental influences such as teratogens in the formation of these anomalies. We will also examine disruptions in craniofacial development, the influence of epigenetic factors, and how these contribute to the diverse range of craniofacial conditions.

2.1 Genetic factors and craniofacial anomalies

2.1.1 Non-syndromic orofacial clefts

Non-syndromic orofacial clefts (NSOCs) are predominantly influenced by genetic factors, with several key genes identified as contributors to their development. Genetic research has highlighted genes such as *IRF6*, *WNT*, *MSX1*, *PAX7*, and *fibroblast growth factors (FGF)*, which are crucial for the normal development of craniofacial tissues. Genetic variants in these genes can disrupt the complex process of palatal fusion and facial development, leading to clefts in the lip and/or palate. While NSOCs are not typically inherited in a straightforward Mendelian manner, a multifactorial inheritance pattern suggests that multiple genetic variants, when combined, contribute to their occurrence.

Studies have shown that familial history increases the risk of NSOCs, underlining the significant role of genetic predisposition in their development. The identification of specific genetic variants linked to NSOCs has provided valuable insights into the molecular mechanisms underlying these conditions. For example, variants in the *IRF6* gene have been found to be particularly relevant in populations with high incidence rates of clefts, whereas mutations in this gene are responsible for the development of Van der Woude syndrome, a condition characterized by cleft lip and/or palate along with lower lip pits. Furthermore, advancements in genomic technologies and transcriptomic profiling have made it possible to screen for causative variants more effectively, allowing for early detection and personalized care strategies.

The cranial neural crest is essential for the formation of craniofacial structures, such as the face, jaw, and skull. In non-syndromic orofacial clefts (NSOCs), abnormalities in the development and migration of cranial neural crest cells are a key factor. These cells contribute to the formation of facial tissues, and disruptions in their signaling pathways can result in clefts. Genetic variants affecting the neural crest and its molecular signals, such as FGF, SHH, and bone morphogenetic proteins (BMP) pathways, can interfere with normal craniofacial development, leading to malformations. A deeper understanding of these genetic factors is critical for improving diagnostic methods, enabling early detection of at-risk individuals, and developing targeted treatments. By identifying the specific genes and signaling pathways involved, it may be possible to create more personalized treatment approaches, ultimately improving the outcomes for patients with NSOCs [6–8].

2.1.2 Syndromic orofacial clefts

Syndromic orofacial clefts often stem from genetic mutations impacting cranial and facial bone formation. Syndromes such as Treacher Collins, Crouzon, and Pierre Robin sequence are linked to specific gene mutations that disrupt the development of facial bones and soft tissues. For example, mutations in the *TCOF1* gene in Treacher Collins syndrome affect neural crest cell migration, leading to underdevelopment of facial bones. Similarly, mutations in *FGFR2* and *FGFR3* in Crouzon syndrome impair cranial suture formation, resulting in premature fusion and craniofacial malformations.

The anterior calvarium, derived from neural crest cells, is particularly vulnerable to disruptions in developmental pathways. Loss of Cox2 function, critical for prostaglandin E2 synthesis, impairs cell migration and differentiation, while Wnt/beta-catenin and Erk signaling regulate the fate of neural crest-derived mesenchyme. Disruption in these pathways can lead to ectopic cartilage or abnormal bone formation in the calvarium. These syndromes frequently exhibit autosomal dominant inheritance, where a single gene mutation suffices to cause the condition. Understanding these genetic and molecular mechanisms enhances our ability to diagnose and develop targeted interventions for these complex craniofacial anomalies [8].

2.2 Environmental and teratogenic influences

2.2.1 Non-genetic factors

While genetic factors significantly contribute to craniofacial anomalies, environmental influences also play a critical role, especially during key stages of embryonic development. Teratogens—agents that interfere with normal fetal development—can lead to structural abnormalities, including cleft lip and palate. Maternal smoking, alcohol consumption, and certain medications are among the most significant environmental factors linked to these conditions.

Exposure to alcohol during pregnancy is strongly associated with fetal alcohol spectrum disorders (FASD), which can cause distinctive craniofacial abnormalities such as microcephaly, flattened facial features, and growth delays. Similarly, maternal smoking disrupts cellular growth and differentiation in the developing embryo, increasing the risk of cleft lip and palate. Certain medications, notably antiepileptic drugs like valproate, have also been linked to congenital craniofacial malformations due to their impact on the development of craniofacial structures [8–10].

2.2.2 Disruption in craniofacial development

The process of craniofacial morphogenesis relies on complex cellular interactions and signaling pathways involving molecules such as bone morphogenetic proteins (BMPs), sonic hedgehog (SHH), and fibroblast growth factors (FGFs). Disruptions in these pathways, whether genetic or environmental, can result in abnormalities like craniosynostosis or clefting. Craniosynostosis, the premature fusion of skull sutures, alters normal skull growth and can be isolated, but in many cases, it occurs as part of genetic syndromes, such as Crouzon syndrome, Apert syndrome, and Pfeiffer syndrome, all of which involve mutations in the FGFR genes.

Maternal lifestyle factors, combined with genetic susceptibilities, amplify the risk of anomalies, underscoring the importance of understanding these interactions for effective prevention and treatment strategies [8–10].

2.3 Epigenetic and molecular factors

Congenital malformations arise from the interplay of genetic predispositions and environmental teratogens, with the epigenome acting as a critical bridge between these influences. Epigenetic mechanisms, including DNA methylation and histone modifications, modulate chromatin organization and gene activity without altering the DNA sequence, playing a pivotal role in embryogenesis. Crucial windows of epigenetic reprogramming occur during early post-fertilization stages and the development of primordial germ cells, directing processes such as cell differentiation and lineage determination.

Maternal metabolic conditions like diabetes and obesity significantly influence fetal development, including the likelihood of orofacial clefts, through epigenetic disruptions. Pre-gestational diabetes subjects the fetus to hyperglycemia and hyperinsulinemia, leading to oxidative stress and hypoxic conditions that alter DNA methylation in genes essential for craniofacial and neural crest development. This increases the risk of congenital anomalies, such as cleft lip and palate, as well as cardiac defects.

Gestational diabetes also contributes to an increased risk of developmental anomalies, although its effects on orofacial clefts tend to be less pronounced than those of pre-gestational diabetes. Large-scale studies highlight an elevated risk of all subtypes of orofacial clefts in infants born to mothers with either form of diabetes. Epigenetic changes, such as DNA methylation alterations and histone acetylation, are implicated in these processes. Maternal hyperglycemia disrupts key signaling pathways, including Wnt, which governs cell proliferation, migration, and apoptosis during craniofacial development. Oxidative stress induced by diabetes impairs specific Wnt pathways and activates signaling inhibitors, adversely affecting palatal formation.

The growing prevalence of maternal obesity poses additional challenges, as it increases the risk of pregnancy complications and developmental abnormalities. Obesity-induced epigenetic changes, such as altered histone acetylation and reduced dimethylation, disrupt critical developmental pathways and may predispose offspring to lifelong metabolic disorders. Maternal obesity's impact on histone acetylation enzymes

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within the intrauterine environment further impairs the development of craniofacial structures and other organs, contributing to the formation of cleft lip and palate.

Maternal dyslipidemia and hypertension have also been associated with an elevated risk of orofacial clefts. The metabolic state of the mother during pregnancy exerts a profound influence on the epigenetic profile of the fetus, linking these changes to congenital anomalies. Addressing the interplay between maternal metabolic health and epigenetic regulation is essential for preventing such defects. Optimizing maternal metabolic health before and during pregnancy is crucial for reducing the incidence of orofacial clefts and other developmental anomalies [11–13].

2.4 Conclusion

The pathophysiology of craniofacial anomalies involves a complex interplay of genetic, environmental, and epigenetic factors that disrupt normal craniofacial development. Continued advancements in molecular and genetic research are shedding light on the intricate mechanisms underlying these conditions, paving the way for improved prevention, diagnosis, and treatment strategies. A comprehensive understanding of these factors is crucial for developing targeted interventions and providing holistic care to individuals affected by craniofacial anomalies. By integrating insights from diverse scientific disciplines, we can enhance patient outcomes and foster progress in managing these challenging conditions.

3. Clinical assessment and diagnosis of craniofacial anomalies

This section discusses the clinical assessment and diagnosis of craniofacial anomalies, focusing on cleft lip and palate. It highlights key diagnostic methods, classification systems, and the identification of functional impairments and dental anomalies that inform effective treatment planning. Additionally, the role of imaging studies in evaluating craniofacial structures is mentioned.

3.1 Embryological development of cleft lip and/or palate

Cleft lip and palate result from disruptions during embryonic development, typically occurring between the 4th and 12th week of gestation [1]. The formation of the lip and palate can be divided into two critical phases during embryogenesis:

- Early development (4–8 weeks of embryonic development)

The initial stages of facial development begin with the formation of the pharyngeal arches, which are structures that contribute to the formation of the face and neck. The first pharyngeal arch differentiates into the maxillary and mandibular processes, which are crucial for lip formation. By Carnegie stage 11, which corresponds to approximately 5–6 weeks of gestation, the bilateral mandibular arches that will form the lower lip become visible. These arches merge completely by Carnegie stage 15 (around 7–8 weeks). The components of the upper lip, including the medial nasal prominence and maxillary process, start to appear around Carnegie stage 16 (approximately 8 weeks) and fully merge by Carnegie stage 20 [14, 15].

- Palate development (9–12 weeks of embryonic development)

The secondary palate develops from palatal shelves that grow vertically along either side of the tongue. These shelves elevate and fuse at the midline, beginning around week 9. This fusion occurs from anterior to posterior, starting at the incisive foramen and concluding with uvular fusion by week 12. Disruptions during this critical fusion process can lead to cleft palate, which may occur with or without associated cleft lip [14, 15].

3.2 Classification of cleft lip and/or cleft palate

Orofacial clefts can be classified based on their anatomical location, severity, and whether they occur as part of a syndrome [1].

- Anatomical classification

The LAHSAL classification system is widely used to describe the cleft's location. It divides the upper lip (L), alveolus (A), hard palate (H), and soft palate (S) into six anatomical segments. Each segment is marked with an uppercase letter for a complete cleft or a lowercase letter for an incomplete cleft, while the absence of a cleft is denoted with a hyphen [16].

- Unilateral vs. bilateral

Orofacial clefts are categorized as unilateral (affecting one side) or bilateral (affecting both sides). Unilateral clefts are more common and often affect the left side [17].

- Complete vs. incomplete

A cleft can also be classified as complete, extending through the entire structure (e.g., lip and palate), or incomplete, affecting only a portion of the structure.

- Syndromic vs. non-syndromic

Approximately 70% of cases are non-syndromic, occurring as isolated anomalies. The remaining 30% are associated with syndromes, such as Pierre Robin sequence or Treacher Collins syndrome [14].

3.3 Clinical examination and diagnostic tools for craniofacial anomalies

Antenatal 2D ultrasonography (US) with morphology examination between the 20th and the 22nd week of gestation is an important pregnancy screening tool in the detection of orofacial inborn malformations. This imaging modality helps identify craniofacial anomalies such as cleft lip, though its sensitivity for cleft palate is lower due to the limitations in visualizing the soft palate. Advances in 3D and 4D ultrasonography have enhanced the diagnostic accuracy, providing clearer images and aiding in the prenatal diagnosis of complex anomalies. These tools allow for better planning of postnatal interventions and parental counseling [18].

Postnatally, a thorough clinical examination remains essential for diagnosing craniofacial anomalies. This includes a detailed assessment of the facial symmetry, oral cavity, and palate integrity. Tools such as nasopharyngoscopy or endoscopy can be utilized to visualize the airway and soft palate for submucosal clefts or other anomalies.

Imaging techniques, including computed tomography (CT) and magnetic resonance imaging (MRI), are valuable for assessing the extent of bony and soft tissue involvement. CT scans provide detailed views of the skeletal structure, while MRI is superior for soft tissue evaluation, particularly in complex syndromic cases.

Comprehensive diagnostic approaches are complemented by genetic testing in syndromic presentations to identify associated anomalies [19, 20].

3.4 Dental evaluation in cleft lip and palate

The dental evaluation of patients with cleft lip and palate is essential for ensuring comprehensive oral health and effective treatment planning. These patients often face unique dental challenges, including anomalies in tooth development, malocclusion, and increased risk of dental caries due to difficulties in oral hygiene.

During the dental evaluation, clinicians assess for common anomalies associated with cleft lip and palate, such as hypodontia, microdontia, and abnormalities in tooth morphology. These conditions can impact both function and esthetics, making early identification critical for timely intervention.

Moreover, a strong emphasis on preventive care is vital. Dental professionals should provide education on proper oral hygiene techniques tailored to the specific needs of cleft patients. Regular dental checkups are crucial for monitoring oral health and addressing any emerging issues promptly. A multidisciplinary approach involving pediatric dentists, oral surgeons, and orthodontists is often necessary. This collaboration ensures that all aspects of the patient's dental health are considered, particularly when planning for surgical interventions or orthodontic treatments later in life. Dental evaluation is fundamental for managing the unique challenges faced by patients with cleft lip and palate, promoting optimal oral health [21].

4. Orthodontic treatment modalities for craniofacial anomalies

Orthodontics plays a pivotal role in the comprehensive management of craniofacial anomalies, addressing both functional and esthetic concerns. In this section, we will explore a range of orthodontic treatment modalities specifically designed to meet the unique needs of patients with craniofacial anomalies.

4.1 Presurgical orthodontics

The purpose of presurgical orthodontics is crucial for preparing the dental arch before surgical interventions. This phase aims to align teeth and create adequate space for procedures like alveolar bone grafting in patients with cleft lip and palate.

This may involve the use of fixed appliances or removable devices to achieve optimal positioning prior to surgery [19]. Nasoalveolar molding (NAM) is one of the common presurgical infant orthopedic techniques used in the treatment of cleft lip and palate. It involves the application of controlled forces to the maxillary segments through an intraoral appliance combined with extraoral nasal stents and adhesive tape. The aim of NAM is to mold the alveolar ridges and nasal cartilage before surgical lip closure, typically performed within the first 4–6 months of life.

NAM reduces the anterior cleft width and narrows both the anterior and medial maxillary widths. The medial rotation of the maxillary segments is a key feature of NAM. This medial movement is achieved through transverse forces generated by the external taping system, which draws the segments together. As a result, the cleft is approximated, and soft tissue convergence is promoted before surgery [22].

Medial rotation of the maxillary segments in NAM is more pronounced than in passive approaches. This rotation reduces transverse distances between the alveolar segments and can result in less sagittal elongation of the maxilla. The reduced sagittal maxillary length is associated with the greater inward rotation of the segments, which redirects growth rather than eliminating it.

NAM also affects the morphology of the nasal cartilage. By using nasal stents, the technique provides early nasal molding, improving the symmetry and shape of the nasal structures. This is particularly beneficial in the correction of nostril height and alar base positioning, contributing to more balanced nasal esthetics after surgical repair [22–24].

NAM can facilitate surgical closure by narrowing the cleft and aligning the soft tissues, reducing tension during repair and potentially minimizing postoperative scarring, which is illustrated as a positive effect in general surgical studies [23, 24]. Improved tissue approximation may also contribute to better wound healing and surgical outcomes. Additionally, early intervention in nasal cartilage shaping can reduce the need for secondary rhinoplasty procedures.

The influence of NAM is primarily observed in the short term, during the presurgical phase. Its long-term effects on maxillary development, dental arch form, and need for future orthodontic or surgical intervention remain subjects for further evaluation [22].

4.2 Comprehensive orthodontic treatment

Comprehensive treatment is typically initiated once skeletal growth is complete, often during late adolescence or early adulthood. This phase involves a full course of orthodontic therapy using fixed appliances, clear aligners, or functional appliances to correct malocclusions and enhance dental esthetics [25].

4.3 Distraction osteogenesis

Distraction osteogenesis is indicated where significant skeletal discrepancies exist, such as hemifacial microsomia or severe maxillary hypoplasia. This innovative technique involves surgically cutting the bone and gradually distracting the segments apart using a device, allowing new bone to form in the gap created over time [26].

4.4 Maxillary expansion

Maxillary expansion is often necessary for patients with narrow maxilla, which typically occurs in orofacial cleft patients. Rapid maxillary expansion is commonly employed to widen the maxilla, creating space for proper alignment of teeth [27].

In growing cleft patients, successful correction of skeletal class III malocclusion and concave facial profiles often requires a combination of maxillary expansion and reverse headgear therapy. Maxillary expansion addresses the transverse maxillary deficiency commonly seen in cleft lip and palate cases, while reverse headgear promotes forward movement of the maxilla to correct anteroposterior discrepancies [28, 29]. This orthopedic approach not only improves skeletal relationships but also contributes to favorable changes in dental alignment and soft tissue profile, particularly enhancing upper lip protrusion [29]. Compared to noncleft individuals, cleft patients may experience greater maxillary advancement and mandibular rotation during protraction therapy, possibly due to anatomical factors such as the absence of firm palatal sutures and scar-related tissue behavior [28]. These combined effects result in improved maxillomandibular balance and more harmonious facial esthetics, though long-term stability of outcomes requires further follow-up [29].

5. Role of surgical intervention in craniofacial anomalies

In this section, the importance of surgery in the treatment of craniofacial anomalies is discussed, especially focusing on procedures such as cleft lip and palate repair, orthognathic surgery, and bone grafting.

5.1 Common surgical procedures

5.1.1 Cleft lip and palate repair

Typically performed within the first year of life for cleft lip repair and around 9 to 12 months for cleft palate repair. The surgery involves closing the gap in the lip or palate and reconstructing the normal anatomy to restore function and appearance [30].

5.1.2 Craniosynostosis surgery

This procedure is indicated when one or more sutures in an infant's skull fuse prematurely, leading to abnormal head shape and potential intracranial pressure. The surgery involves removing the fused suture and reshaping the skull to allow for normal brain growth [31].

5.1.3 Distraction osteogenesis

This technique is used for patients with significant skeletal discrepancies, such as hemifacial microsomia or severe maxillary hypoplasia. It involves surgically cutting the bone and gradually distracting the segments apart using a device, allowing new bone to form in the gap over time [32].

5.1.4 Orthognathic surgery

Performed on adolescents or adults with jaw discrepancies that cannot be corrected through orthodontics alone. This surgery repositions the upper or lower jaw to improve occlusion and facial esthetics in severe skeletal discrepancies [33].

5.2 Challenges in surgical intervention

While surgical intervention can lead to significant improvements, several challenges must be addressed. Especially, determining the optimal timing for surgical interventions is crucial. Early surgeries may improve functional outcomes but must be balanced against potential risks and complications. What is more, each patient presents unique anatomical variations that require individualized surgical planning. Surgeons must carefully assess these factors to achieve optimal results.

Patients with craniofacial anomalies often require long-term follow-up care to monitor growth, development, and any potential complications from surgeries [34].

6. Multidisciplinary approach to treatment

This section discusses the importance of a multidisciplinary approach in the management of craniofacial anomalies, emphasizing how collaboration among various healthcare professionals can lead to optimal patient outcomes.

6.1 Key disciplines involved

A successful multidisciplinary team typically includes plastic surgeons, orthodontists, oral surgeons, speech therapists, and psychologists.

- *Plastic surgeons* are crucial for performing reconstructive surgeries, such as cleft lip and palate repair and craniosynostosis surgery.

- *Orthodontists* play a significant role in managing dental alignment and occlusion. They collaborate closely with surgeons to develop pre- and post-surgical orthodontic treatment plans, ensuring that teeth are properly aligned before surgery and maintained afterward.

- *Oral surgeons* specialize in surgical procedures involving the facial part of the skull. They often perform orthognathic surgery to correct skeletal discrepancies that cannot be addressed through orthodontics alone.

- *Speech therapists* assess communication challenges and provide targeted therapy to improve articulation and language skills, which is crucial for enhancing the patient's quality of life.

- *Psychologists* offer support to patients and their families, addressing the emotional challenges associated with living with a craniofacial condition [35, 36].

6.2 Benefits of a multidisciplinary approach

The multidisciplinary approach offers numerous advantages. A team of specialists ensures that all aspects of a patient's condition are addressed, from surgical correction to orthodontic alignment and speech development. A multidisciplinary team can develop tailored treatment plans that optimize care for each individual, whereas including psychologists and social workers ensures that patients receive holistic care that addresses their physical, emotional, and social well-being. As advancements in medical technology continue to evolve, fostering strong interdisciplinary collaboration will remain vital in providing high-quality care for affected individuals and their families, highlighting the importance of a collaborative approach [35, 36].

7. Impact of craniofacial anomalies on social and psychological well-being

This section explores the significant impact of craniofacial anomalies on the social and psychological well-being of affected individuals. Conditions such as cleft lip and palate can lead to various challenges, including difficulties in social interactions, increased levels of anxiety and depression, and a higher risk of bullying and social isolation.

7.1 Social challenges

Children with craniofacial anomalies often face unique social pressures, particularly during formative years in elementary school. Research indicates that elementary school children with clefts exhibit the highest levels of anxiety and depression compared to their peers in middle and high school. This age group is particularly vulnerable to peer interactions, which can be fraught with challenges due to their visible differences. Studies highlight that children may struggle with socialization, leading to feelings of exclusion and difficulties in forming friendships. The stigma associated with their appearance can result in bullying and teasing, further exacerbating their social challenges [36, 37].

7.2 Psychological effects

The psychological impact of craniofacial anomalies is profound. Children and adolescents with these conditions often experience heightened levels of anxiety and depression. The psychosocial functioning of youths with clefts who underwent reconstructive surgery showed improvements in areas such as peer relationships and emotional well-being. However, the psychological effects can persist long after surgical interventions, indicating a need for ongoing support. The emotional toll of living with a craniofacial anomaly can lead to issues such as low self-esteem and body image concerns. Individuals may become acutely aware of their differences, leading to social withdrawal or avoidance behaviors. The visibility of their condition can make them targets for negative social interactions, impacting their overall mental health [36, 37].

7.3 The role of support systems

Support systems play a crucial role in mitigating the negative effects of craniofacial anomalies. Parents, educators, and healthcare providers must work together to create an environment that fosters acceptance and understanding. Educating peers about craniofacial conditions can help reduce stigma and promote inclusivity. Schools should implement programs that encourage empathy and support for children with visible differences. Moreover, psychological support through counseling or therapy can be beneficial for individuals coping with the emotional challenges associated with clefts. Mental health professionals can provide strategies to improve self-esteem, enhance coping mechanisms, and facilitate better social interactions [36, 37].

8. Future directions and challenges in craniofacial anomaly care

The care of individuals with craniofacial anomalies is evolving, presenting both promising advancements and significant challenges. The future of craniofacial anomaly care is being significantly shaped by advancements in 3D technologies. Moreover, future directions include the establishment of global registries to collect comprehensive data on prevalence, treatment outcomes, and long-term effects, which will inform evidence-based practices and resource allocation. Enhancing interdisciplinary collaboration among healthcare providers—such as plastic surgeons, orthodontists, speech therapists, and psychologists—is crucial for developing coordinated care plans that address both physical and psychosocial needs. Integrating mental health support into treatment models is essential, as patients often face emotional and social challenges that can impact their overall well-being. While advancements in cleft care are encouraging, addressing these challenges through improved data collection, collaboration, and holistic support will be vital for optimizing patient outcomes and enhancing the quality of life for individuals with craniofacial anomalies. Continued research and cooperation among healthcare professionals will play a key role in shaping the future landscape of cleft care [4, 6].

9. Conclusion and implications for practice

To summarize key points from the chapter, it is crucial to emphasize the role of orthodontics and multidisciplinary care in improving the outcomes and quality of life for patients with craniofacial anomalies. The management of craniofacial anomalies requires a comprehensive and multidisciplinary approach that addresses both the physical and psychosocial aspects of care. Advances in surgical techniques, 3D technologies, and interdisciplinary collaboration have significantly improved treatment outcomes and quality of life for affected individuals.

The implications for practice are clear: healthcare professionals must prioritize collaboration across disciplines—such as plastic surgery, orthodontics, speech therapy, and psychology—to develop coordinated care plans tailored to each patient's unique needs. Establishing global registries will facilitate research and inform evidence-based practices, ultimately leading to improved resource allocation. Furthermore, integrating psychosocial support into treatment models is essential to address the emotional challenges faced by patients with orofacial clefts. Continuous research and innovation will be vital in shaping future care strategies and improving outcomes for this population.

Conflict of interest

The authors declare no conflict of interest.

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Chapter 6

Modern Approaches to Children's Oral Health: Contemporary Risk Factors and the Influence of Parental Education

Ruxandra Sava-Rosianu, Ramona Dumitrescu and Atena Galuscan

Abstract

Children's oral health is shaped by various contemporary risk factors that extend beyond genetics, with lifestyle habits, diet, and environmental influences playing a significant role. One of the most pressing concerns today is the high consumption of sugary foods and drinks, which significantly contributes to the prevalence of dental caries among young children. Additionally, digital media and sedentary behaviors can indirectly affect oral health by encouraging unhealthy dietary patterns. Parental education is a key determinant in the oral health outcomes of children. Well-informed parents are more likely to implement preventive measures, such as regular dental check-ups, proper oral hygiene routines, and a healthy diet. Conversely, parents with lower levels of education may lack the awareness or resources to foster good oral health habits in their children, leading to higher rates of dental issues. A modern approach to children's oral health emphasizes preventive care, early intervention, and educating both parents and children on the importance of oral hygiene. This approach also encourages collaboration between dental professionals, pediatricians, and educators to create a supportive environment for long-term health. By addressing contemporary risk factors and empowering parents with knowledge, the path toward improved oral health in children becomes more attainable.

Keywords: oral health, dental caries, preventive care, parental education, healthy diet

1. Introduction

Children's oral health faces a myriad of modern challenges, shaped by evolving lifestyles, dietary habits, and environmental factors. Issues such as the rising prevalence of dental caries, poor oral hygiene, and their connections to systemic health have become increasingly significant in today's context. These challenges are exacerbated by high consumption of sugary foods, inadequate preventive care, and disparities in access to dental services. Addressing these issues early is critical, as poor oral health in childhood can lead to long-term health complications, including chronic diseases and diminished quality of life. Early intervention and prevention, supported by parental education, community awareness, and collaboration among healthcare professionals, are pivotal in mitigating these risks and ensuring children maintain healthy oral habits that last a lifetime. This chapter explores the contemporary issues affecting children's oral health and emphasizes the essential role of proactive strategies in fostering healthier outcomes.

2. Understanding contemporary risk factors

2.1 Impact of sugary foods and beverages on dental caries

In the twenty-first century, oral diseases, particularly dental caries, continue to be a significant public health challenge. While progress has been made in improving oral health in many parts of the world, effectively managing these diseases requires a combination of preventive dentistry, self-care practices, and active individual participation. Recognizing that numerous health determinants lie beyond personal control; public dental health systems have a critical role in supporting and enabling individuals to take proactive steps toward oral health. Addressing diverse populations with varying needs, alongside adapting to changing epidemiological trends, necessitates constant innovation and responsiveness from public dental health sectors. Similarly, the field of nutrition, a key factor in oral health, is continually evolving, underscoring the need for ongoing education of health professionals. Public dental health teams are pivotal in providing nutrition education and facilitating its application to promote healthier dietary habits and improve overall oral health outcomes.

The food and beverage industry has strategically designed products to maximize consumer appeal, with sugar-sweetened beverages such as soft drinks, fruit juices, chocolate milk, and energy drinks serving as prime examples. These beverages are crafted to heighten consumer attraction through elevated carbohydrate content, which boosts blood glucose levels and induces a pleasurable mood. Additionally, caffeine in many of these drinks stimulates the trigeminal nerve, often working synergistically with carbonic acid to enhance the sensory experience. However, these pleasurable effects come with significant health risks. The high caffeine and phosphorus content in many of these drinks has been linked to potential bone loss, while the excessive acidity, with pH levels ranging from 2.4 to 3.5, poses a substantial threat to dental health. Energy drinks, in particular, are associated with severe oral health risks due to their high sugar and acid content, which include carbonic, phosphoric, malic, and citric acids. Prolonged and frequent consumption of these beverages has been shown to significantly contribute to the development of dental caries. Their acidity exacerbates the carious process by intensifying the acidic environment in the oral cavity and promoting the growth of acidogenic and aciduric microbiota. Studies have consistently established a positive correlation between the frequency of soft drink consumption and the severity of dental caries. Shifts in beverage consumption patterns among younger populations, with an increased preference for sugary and acidic drinks over traditional beverages like water, milk, and juice, further underscore the public health challenge. Nevertheless, some beverages like tea, which contains high levels of polyphenols, have demonstrated caries-preventive properties, offering a healthier alternative to energy drinks. Recent trends in green marketing within the food industry have spurred advancements in the nutritional value of products, particularly those targeting children. Innovations like enriched pasta with vegetables aim to help children meet daily vegetable requirements and improve nutrient bioavailability. These developments have potential benefits for oral health, as nutrients like calcium and magnesium play a crucial role in caries prevention. Efforts to reduce sugar content in foods for children aged 4–10, as well as in infant formulas, have also been notable. Manufacturers are adopting guidelines to limit sugars, carbohydrates, and corn syrup in these products while incorporating beneficial components like fructo- and galacto-oligosaccharides to enhance the oral health outcomes. To address consumer confusion about nutrient content and mitigate the risks of overconsumption, health professionals recommend front-of-package color-coded labeling systems. These labels categorize products based on health impact, with "red" signaling caution and limited consumption, while "green" and "amber" encourage healthier choices. This strategy aims to empower consumers to make informed decisions, reduce the risk of caries, and improve overall oral health [1].

2.2 Promoting a balanced, low-sugar diet for children

Maintaining a healthy body begins with a balanced and nutritious diet, which is equally essential for oral health. Adequate intake of vital nutrients and vitamins is crucial for a healthy mouth. However, the growing prevalence and promotion of processed and sugary foods, particularly among adolescents, is a cause for concern. Studies highlight that childhood malnutrition can impair proper tooth development and weaken immune function by reducing salivary flow, thereby increasing vulnerability to dental caries. Nutrition also plays a significant role in oral health by influencing not only dental decay and enamel erosion—often linked to dietary acids and sugars found in soft drinks—but also craniofacial development, oral cancer, and other oral infections [2]. Adopting healthy oral behaviors significantly reduces the risk of dental caries and has played a major role in the decline of caries rates observed in the developed countries over the past two decades. Research examining the impact of various food types on oral health has revealed that not all dietary components are directly linked to caries prevalence or restoration indices. Notably, carbonated soft drinks and cocoa consumption exhibit distinct relationships with oral health outcomes. Carbonated soft drinks are directly proportional to an increase in dentinal caries index and inversely proportional to the restoration index, suggesting a segment of the population for whom neither preventive measures nor dental treatments are prioritized. Frequent consumption of carbonated soft drinks is strongly associated with a higher number of caries, whereas high cocoa intake correlates with an increased number of dental restorations. Additionally, complementary consumption of candies, milk, and tea shows a positive correlation with caries prevalence in the analyzed sample. However, no significant correlation was observed between the indices for caries or restorations and the consumption of fruits or pastries. These findings underline the critical role of dietary habits in influencing oral health, particularly in promoting a balanced, low-sugar diet for children to mitigate the risk of caries development and foster better dental outcomes [3].

2.3 Educating parents and children about healthy food choices

Early preventive measures, such as promoting healthy eating habits in children and adolescents, are essential for overall well-being. Diet counseling for parents or caregivers during dental visits forms an integral part of anticipatory guidance.

Since young children depend on caregivers for food choices, fostering healthy habits at an early age is critical. As children enter adolescence, they assume greater autonomy over their dietary decisions, making it imperative to instill sound nutritional practices early. Parents can adopt specific guidelines to reduce the risk of dental caries, such as avoiding bedtime bottles and limiting cow's milk during the first year of life [2]. The home food environment plays a pivotal role in shaping children's eating behaviors and dietary habits, influencing both the availability and accessibility of food. These factors determine what children eat, as most of their meals are prepared and consumed at home. Availability refers to the physical presence of food in the household, while accessibility involves parental actions that regulate how easily children can obtain specific foods. However, socioeconomic factors, such as lower income, can limit access to healthy foods and lead to greater consumption of fast foods due to perceived lower costs [4].

2.4 Addressing cultural and socioeconomic factors affecting diet

Dietary risks were responsible for over one-third of global deaths in 2013, highlighting the importance of nutrition in preventing non-communicable diseases. The World Health Organization (WHO) has targeted nutritional behaviors to address the rising burden of these diseases. Adolescence and early adulthood are critical life stages where health behaviors, including dietary habits, are established and may have long-term implications for health. During these periods, significant behavioral changes occur, and pre-existing habits can either be reinforced or modified.

Socioeconomic disparities in health, including nutrition, have been increasingly observed in Europe and the USA. Higher socioeconomic status (SES)—characterized by education, income, and employment—is associated with healthier dietary patterns, such as increased consumption of whole grains, fruits, vegetables, and low-fat dairy products, and decreased intake of unhealthy items like refined grains and added fats. Conversely, lower SES is often linked to poorer dietary quality, including higher consumption of sugar-sweetened beverages (SSBs) and less frequent intake of nutrient-dense foods. Maternal education, in particular, has been identified as a strong determinant of children's dietary quality, with parental marital status also influencing SSB consumption. Additionally, factors like ethnicity, migration background, and place of residence further complicate the understanding of these disparities. Interactions between SES characteristics and individual factors, such as age, sex, and family conditions, require nuanced interpretation to accurately assess their impact on dietary behaviors [5].

2.5 Role of sedentary lifestyles and digital media in dietary patterns

Childhood and adolescence are critical periods for the development of obesity, which often persists into adulthood and is associated with numerous health complications, including those affecting oral health. Obesity during adolescence has been linked to an increased risk of premature mortality, even after adjusting for adult body mass index (BMI), as demonstrated in large cohort studies. For instance, findings from the Nurses' Health Study II, involving over 102,000 women, highlighted increased mortality rates among women with a BMI as low as 22.0 to 24.9 kg/m^2. The origins of obesity are multifactorial, influenced by both genetic and environmental factors. However, the rapid rise in obesity rates to epidemic levels underscores the significant role of environmental influences, such as diet and lifestyle. Diets high in sugars and refined carbohydrates not only contribute to obesity but also significantly impact oral health, increasing the risk of dental caries. A lack of accurate methods to measure energy intake and expenditure has complicated efforts to pinpoint the exact balance between dietary habits and energy use, further complicating our understanding of obesity's root causes. Sedentary behaviors, particularly in children and adolescents, exacerbate the problem. Increased use of information and communication technology, including television viewing, computer use, and video gaming, has been strongly linked to obesity prevalence, as these activities often correlate with snacking on unhealthy foods and beverages high in sugar. Such dietary patterns not only promote weight gain but also contribute to poor oral health, including enamel erosion and caries. In Spain, for example, a significant proportion of teenagers—especially boys—own video game consoles and computers, and nearly all families have multiple televisions in their homes. Cross-sectional studies have consistently shown a relationship between high television viewing hours and increased obesity rates. However, video gaming appears to have a weaker association with obesity, potentially due to its different patterns of physical activity engagement. Oral health is intricately tied to these dietary and lifestyle factors. A high intake of sugary and acidic foods and drinks, often consumed during screen time, creates a perfect storm for both obesity and dental caries. Prolonged exposure to sugar and low pH levels in the oral cavity facilitates cariogenic activity, while the sedentary behaviors associated with these dietary habits contribute to weight gain. Addressing these interconnected issues requires a dual focus on promoting healthier diets that support both oral and systemic health and reducing sedentary lifestyles in children and adolescents [6].

3. The impact of digital media on oral health habits

3.1 How screen time influences dietary and oral hygiene practices?

Health authorities generally agree that excessive screen time negatively impacts childhood development. Current guidelines from the American Academy of Pediatrics (AAP) recommend that children under 2 years old should not use electronic media at all, while those over 2 years old should be limited to less than 2 hours per day. Similarly, the Australian Department of Health adopts even stricter criteria, advising less than 1 hour of screen time daily for children aged 2 to 5 years [7]. However, data from the International Children's Accelerometry Database (1997–2009) revealed that around two-thirds of children did not adhere to these screen time recommendations [8]. With the rapid growth of technological devices in recent years, electronic media has become an integral part of daily life, and adherence to these guidelines is presumed to have declined further [9]. Research suggests that children are exposed to screens from a very young age, with estimates indicating they spend a significant portion of their waking hours—often up to 8 hours daily—engaged in screen-based activities [10–12]. In fact, an AAP newsletter from late 2015 highlighted that existing screen time guidelines for children might be outdated, noting that roughly 90% of parents do not follow the AAP's recommendations [7]. Many parents continue their current screen time practices because they believe media content has educational value. For example, one survey found that 29% of parents interviewed allowed children under 2 years old to watch television, believing it to be beneficial for their brain development. Other parents reported not restricting screen time to avoid conflicts, prevent social isolation, or simply to entertain or distract their children. Studies have shown that parents often use television to keep children occupied while managing household tasks or rely on mobile media to entertain children during activities like dining out [13, 14]. Research indicates a clear link between screen time, particularly television viewing, and unhealthy dietary habits. Additionally, screen time is associated with a range of physiological and psychological challenges, including increased adiposity, unhealthy diets, depressive symptoms, and reduced quality of life. However, the relationship between screen time and other health outcomes, such as cardiovascular risk and physical fitness, remains less conclusive. While most studies focus on television use, limited evidence exists on the impact of newer screen activities like computer use, video games, and mobile phones. This lack of data underscores the need for further exploration into how evolving screen use patterns influence children's health [15].

Increased screen time has been consistently associated with obesity, driven by mechanisms such as higher caloric intake, reduced resting metabolism, shorter sleep duration, and decreased physical activity as time is reallocated to screen-based activities [16]. Gender differences have also been noted, with boys generally spending more time on video games compared to girls. Obesity in childhood is a critical public health concern, given its role as a risk factor for non-communicable diseases, including cardiovascular diseases, type 2 diabetes, musculoskeletal disorders, and certain cancers [17]. Screen use has also been linked to obesity and oral health [18, 19]. Longer durations of television viewing have been significantly associated with a higher number of decayed teeth and an increased DMF index ("decayed, missing, and filled"). Oral health behaviors play a critical role in physical and psychosocial well-being, influencing factors such as dietary habits, communication abilities, and overall comfort. Poor oral health is associated with pain, functional limitations, and esthetic dissatisfaction, which affect quality of life. Both caries and obesity share similar risk factors, including diet, genetic predisposition, socioeconomic status, environmental influences, and lifestyle habits [20]. Studies have explored the relationship between body weight and dental caries, as these conditions often stem from shared dietary patterns. While some research has identified a connection between dental caries and body mass index (BMI), results have been mixed or contradictory [21]. However, many studies indicate that overweight and obese schoolchildren exhibit a higher mean number of dental caries compared to their normal-weight peers. These findings emphasize the interconnectedness of diet and health outcomes, highlighting the need for integrated strategies to address both obesity and oral health [21, 22].

Studies exploring the relationship between media use and oral health have identified type-specific impacts. Excessive video game playing (>2 hours/day) in children aged 6–15 is linked to lower toothbrushing frequency (<2 times/day) and unhealthy dental behaviors, regardless of awareness of dental caries. Prolonged TV viewing in children aged 6–12 is correlated with increased dental caries activity. Among adolescents, problematic internet use is associated with poor oral hygiene practices, including infrequent toothbrushing, gingival bleeding, tooth pain, and neglect of dental checkups. Late adolescents engaging in excessive computer use (>3 hours/day) show neglect in oral hygiene, higher rates of gingivitis, decayed teeth, and periodontal issues. These findings highlight the adverse effects of excessive screen use on oral health across age groups [23–26].

3.2 Encouraging healthy behaviors in a digital age

Deaths from lifestyle diseases are increasing rapidly worldwide, now accounting for 71% of all deaths annually, with 41 million people dying from such diseases each year. These conditions, often stemming from sedentary lifestyles, poor diets, and insufficient physical activity, disproportionately affect individuals in low- and middle-income countries, where 85% of premature deaths (ages 30–69) occur. Among children, the rise in overweight and obesity is alarming. In 2019, an estimated 38.2 million children under 5 were overweight or obese, with nearly half residing in Asia and an increasing prevalence in Africa. Since 2000, the number of overweight children in Africa under 5 has grown by 24%. Previously considered a high-income country issue, childhood obesity is now a significant concern in low- and middle-income urban areas. Obesity in children is linked to the development of other lifestyle diseases, including cardiovascular diseases, type 2 diabetes, and psychological conditions like depression. These conditions impose a significant financial burden on families, communities, and health systems. Addressing these risks requires strategies that encompass detection, treatment, and most critically, prevention.

Digital interventions are emerging as promising tools to address the challenges posed by lifestyle diseases in children. These interventions leverage technology such as smartphones, computers, and wearable devices to deliver personalized, accessible, and cost-effective health solutions. By focusing on behavior change, digital tools can help promote healthier habits in children and their families, addressing critical issues such as diet, physical activity, and mental well-being. The World Health Organization (WHO) highlights four categories of digital health interventions: clients, health care providers, health system managers, and data services. Client-focused digital interventions are particularly valuable for children, providing a range of tools to support healthy lifestyles. These include behavioral change strategies that leverage gamification, motivational messages, and goal-setting to encourage habits like regular physical activity, balanced nutrition, and sufficient sleep. They also foster parental engagement through apps and platforms that allow parents to monitor their children's health behaviors, access educational content, and promote healthier household practices. Additionally, early detection and screening tools, such as wearable sensors and mobile health apps, help track activity levels, sleep patterns, and weight changes to identify early signs of lifestyle-related health issues. Finally, these interventions emphasize education and empowerment by offering interactive digital content designed to engage children and parents in learning about the importance of healthy living.

While digital tools hold immense potential, their effectiveness in children depends on addressing barriers such as digital literacy, privacy concerns, and sustained engagement. Many interventions face low long-term usage rates, with noncommitment being a significant challenge. To be successful, these technologies must not only demonstrate short-term behavior changes but also prove their ability to deliver long-term health benefits. Effectively combating lifestyle diseases in children requires the integration of digital health interventions into broader health systems and educational frameworks. This approach should prioritize comprehensive prevention programs, incorporating digital tools into school curricula to teach children about nutrition and physical activity. Ensuring affordability and accessibility, particularly in low- and middle-income countries where childhood obesity is increasingly prevalent, is essential. To maintain engagement, apps and platforms should be designed to be child-friendly, featuring interactive feedback and gamified elements. Additionally, fostering collaborative ecosystems among technology providers, health professionals, educators, and policymakers is critical to creating cohesive and impactful solutions. By leveraging these strategies, digital technologies can address the root causes of lifestyle diseases in children, paving the way for healthier generations and reducing the global burden of preventable conditions [27].

3.3 Parental guidance in managing children's digital habits

Children today grow up in a digitally interconnected world that offers immense opportunities for learning and development but also presents significant risks to their health and well-being. Challenges such as cyberbullying, digital addiction, unauthorized financial activities, and exploitative online practices are increasingly common, emphasizing the need for robust digital parenting. Parents have a crucial role in safeguarding children's physical, emotional, and psychological health in the digital era. This includes modeling responsible technology use, fostering open communication, and creating secure, age-appropriate digital environments while staying informed about evolving digital trends and risks. Digital parenting, however, should go beyond technical skills to incorporate broader principles of sustainability and lifelong learning. Initiatives like UNESCO's Education for Sustainable Development (ESD) program and the United Nations' 2030 Agenda for Sustainable Development provide a framework for this approach. These programs emphasize the importance of inclusive, high-quality education that empowers individuals to address global challenges, such as the risks posed by the digital environment. In line with the goals, sustainable digital parenting initiatives can enable parents to support their children's health and well-being while fostering responsible digital citizenship. By integrating these global perspectives, digital parenting can be a cornerstone of efforts to ensure a healthier, safer, and more equitable future for children in the digital age [28].

3.4 Environmental influences on oral health

The environment plays a crucial role in shaping health outcomes, particularly for children. Both the social environment—encompassing factors such as social support, income inequality, social cohesion, and racial discrimination—and the built environment, including human-made surroundings, significantly influence health. In the context of oral health, dental caries and fluorosis are key conditions linked to environmental determinants, particularly access to fluoridated water. Dental caries, one of the most prevalent chronic diseases, disproportionately affects around 70% of children from disadvantaged families globally, especially those in rural areas, ethnic minorities, and low socioeconomic positions. The use of fluoride reduces caries that incidence among children in lower socioeconomic areas, where access to dental services and fluoride toothpaste is often limited. Thus, fluoridated water and fluoride-containing products are essential interventions to improve oral health equity for children. Climate change further exacerbates health disparities for children by intensifying existing vulnerabilities. The increasing frequency of extreme weather events, such as heatwaves, storms, and floods, directly impacts children's health through physical injuries, respiratory disorders, and waterborne diseases. Indirectly, climate change disrupts food systems, leading to undernutrition and food insecurity, which are critical concerns for children in developing regions. Moreover, mental health outcomes in children are adversely affected by the stresses of displacement and sociopolitical instability caused by climate-related events. Children, particularly in lower-income families, are disproportionately affected by the health impacts of climate change. Rising temperatures and humidity are linked to infectious diseases, adverse respiratory and cardiovascular conditions, and malnutrition. Additionally, climate-induced health crises often strain healthcare systems, making it even more difficult for children in disadvantaged areas to access the care they need. Addressing the environmental health challenges faced by children requires a multidisciplinary and multi-level approach. Policies must focus on reducing carbon emissions, increasing carbon biosequestration, and stabilizing temperatures to mitigate the long-term effects of climate change. Localized efforts must prioritize adaptation strategies, ensuring that communities—including those most vulnerable—are actively involved in advocacy and decision-making processes. Public health systems must be strengthened to respond effectively to the health challenges posed by environmental changes, with a specific emphasis on protecting and supporting children. Only through coordinated global action can we ensure that children's health and well-being are safeguarded in the face of environmental and climate challenges [29].

4. The role of parental education in oral health outcomes

4.1 How parental awareness impacts children's oral health?

The impact of parental oral health habits and knowledge on their children's oral health are well-established. Poor oral hygiene practices in children significantly increase the risk of developing dental caries. Additionally, low socioeconomic status and inadequate parental oral health behaviors are key contributors to dental caries. Other factors, such as gender and developmental dimensions, also play a role. Given the critical importance of oral hygiene in overall health, it is essential to provide comprehensive guidelines on children's oral health practices and their connection to dental caries. Addressing these complex factors is vital for designing effective public health initiatives that target both children and parents, ultimately improving oral health outcomes and enhancing overall quality of life [30].

Parental oral health behaviors encompass a wide range of practices that significantly influence their children's oral health, both directly and indirectly. Parents act as primary role models for their children, shaping their attitudes and habits toward oral hygiene. When parents prioritize their oral health by attending regular dental appointments, maintaining consistent brushing and flossing routines, and making healthy dietary choices, their children are more likely to adopt these practices. Active parental involvement in a child's daily oral hygiene regimen, especially during formative years, is critical. Parents guide children through the establishment of proper toothbrushing habits that serve as a foundational defense against oral diseases such as dental caries and periodontal conditions. Parents also play a key role in shaping their children's dietary habits that are closely linked to oral health. Diets high in sugary snacks and beverages increase the risk of tooth decay, whereas parents who encourage balanced diets with the limited sugar intake help foster better oral health outcomes. Moreover, parental awareness of preventive measures, such as fluoride treatments and dental sealants, significantly reduces the likelihood of dental issues in children. Regular dental check-ups, encouraged by proactive parents, enable the early identification and treatment of potential dental problems. Parents' own behaviors, such as avoiding harmful habits like smoking or excessive alcohol consumption, not only protect their own oral health but also set a positive example for their children. These healthy behaviors reduce the risk of adverse oral health outcomes and minimize the chances of children adopting harmful habits in the future. Collectively, parents serve as active facilitators in fostering lifelong oral health practices, contributing to the overall well-being of their children [31–33].

The impact of parental oral health behaviors on their children's oral health is significant and multi-faceted. Parents act as role models, educators, and facilitators, shaping healthy oral hygiene practices during their children's formative years. Encouraging parental participation in oral health promotion and prevention programs is essential for improving oral health outcomes for future generations. Public health initiatives should emphasize the importance of parental involvement and provide resources and education to help parents establish and sustain sound oral health practices in their children. Through proactive engagement, parents can play a pivotal role in reducing the prevalence of oral diseases in children and promoting lifelong oral health.

Moreover, the connection between oral health and overall well-being cannot be overlooked. Establishing good oral hygiene practices early in life not only ensures a healthy mouth but also contributes to overall physical and mental health. Children are particularly vulnerable to oral health issues, making parental involvement in oral health promotion even more critical. Parents serve as nurturers and educators, creating a family environment that supports and encourages healthy behaviors. Families that promote healthy choices and maintain trust in the healthcare and dental systems reinforce the value of oral health. Additionally, parents with strong coping skills and confidence in leading healthy lifestyles set positive examples, further enhancing their children's attitudes toward oral hygiene and overall well-being [30].

4.2 Barriers faced by parents with limited education

The education level of parents plays a crucial role in their children's health and well-being. Research indicates that higher parental educational attainment is strongly linked to improved health outcomes for children. This connection is likely due to parents with higher education being better equipped with the knowledge, resources, and access to healthcare necessary for fostering their children's optimal health. Educated parents are more adept at communicating with their children about the risks associated with certain behaviors and providing the guidance and support needed to make healthy choices. Additionally, they are more likely to possess the financial means to ensure their children receive quality education and healthcare. These advantages contribute to better overall health and well-being, which in turn reduces the likelihood of children engaging in risky behaviors [34]. For younger children, the role of parents and primary caregivers is essential in managing and preventing dental caries. Maternal and parental education, attitudes, beliefs, and other psychosocial factors significantly influence parents' oral health practices on behalf of their children. Families with lower levels of education often place less emphasis on dental care practices and routine preventive visits to dental professionals, which can lead to an increased risk of developing dental caries. Parents with higher education levels tend to prioritize their children's oral health and adopt preventive measures more consistently. Conversely, lower levels of parental education are often associated with inadequate attention to dental care, leading to a higher prevalence of dental issues such as caries. Education also correlates with socioeconomic status, which plays a significant role in access to dental care and the adoption of healthy oral hygiene practices. Children from families with well-educated parents are more likely to benefit from better oral care routines and access to necessary treatments, while those from less-educated backgrounds are at greater risk of poor dental health. This underscores the need for targeted educational initiatives aimed at parents with lower education levels to address disparities in oral health. Preventive strategies, particularly those promoting fluoride use through toothpaste, gels, or community programs, are effective tools for reducing dental issues and improving overall oral health among children [35].

5. Preventive care as the foundation of oral health

5.1 Importance of regular dental check-ups

Routine dental visits are essential for maintaining good oral health in children, which is a vital component of their overall health and development. Regular check-ups help prevent common dental issues such as caries and gum disease, ensuring children maintain healthy teeth and gums as they grow. These visits also allow for early detection of potential oral health problems, timely treatment, and the implementation of preventive measures to support long-term dental health. For children, the American Dental Association (ADA) recommends regular dental visits once or twice a year, depending on individual needs, to address their unique oral health requirements. Similarly, the U.K.'s National Institute for Health and Care Excellence (NICE) advises a maximum interval of 12 months between dental exams for patients under 18 years old. The World Health Organization (WHO) also highlights the importance of routine dental care in children as part of its global oral health strategies, promoting prevention and early intervention to reduce the risk of oral diseases. These routine visits not only support physical health but also instill good oral hygiene habits early in life, encouraging children to prioritize dental care as they grow. This proactive approach lays the foundation for healthier smiles and better overall well-being in the future [36].

The differences in level of dental care use and oral health outcomes are influenced by several predisposing factors, such as social status, level of education, occupation, and income [37–42]. A study examining the influence of socioeconomic disparity on oral health also emphasized that individuals with low socioeconomic status face barriers in accessing oral healthcare services, thereby exacerbating social inequalities in oral health outcomes [43]. Moreover, the provision of dental care and the condition of oral well-being are shaped by facilitating factors, including availability, cost of treatment, and the nature of oral health services [41, 44, 45]. Due to these factors, especially in low-income countries, access to dental health care is still scarce [46]. Difficulties in accessing dental care may also arise from avoidance of visiting the dentist due to high treatment costs and financial constraints [47, 48], as well as reduced mobility due to physical and mental disability, particularly among the elderly population.

This bears significant implications, especially for nations contending with limited access to oral healthcare systems [46]. Challenges in obtaining dental treatment may also stem from reluctance to visit the dentist due to exorbitant treatment expenses and financial constraints [46, 47], as well as restricted mobility resulting from physical and mental incapacitation, notably prevalent among the elderly demographic [49, 50]. In such circumstances, the absence of routine dental examinations may worsen oral health issues, leading to more extensive health complications. Furthermore, due to socioeconomic disparities, individuals with higher advantages tend to demonstrate favorable attendance trends and opt for private dental facilities for intricate, tooth-preserving, albeit costly treatments; conversely, disadvantaged individuals often exhibit symptomatic attendance trends and opt for public dental care, which is notably more economical [41].

Oral health-related behaviors play a pivotal role in shaping individuals' dental check-up patterns and oral health status [39, 44, 51]. Patients who only visit the dentist if symptomatic, may harbor distinctive philosophical perspectives regarding the significance of preventive care compared to regular dental attenders. The disparities in oral health status between regular and nonregular attenders could be ascribed to the "healthy user effect," a phenomenon encompassing a set of behaviors conducive to superior health outcomes. These behaviors include being health-conscious, refraining from smoking, practicing moderate alcohol consumption, adopting prudent dietary and hygiene habits, as well as adhering to routine healthcare visits and health screenings. This supports their findings that individuals who engage in frequent toothbrushing [51] and exhibit lower plaque scores [38] tend to manifest improved oral health outcomes, underscoring the impact of the healthy user effect.

However, a research conducted by Listl et al. [52] analyzing data from 13 European nations indicated that the correlation between dental check-up patterns and oral health status is not solely due to the healthy user effect, but rather is causative. Additionally, it is important to acknowledge the link between dental anxiety and oral health. A study included in the analysis revealed that individuals with dental anxiety were more prone to having decayed teeth and reporting poorer oral health. The emergence of dental anxiety is primarily attributed to the anticipation of pain during dental procedures, encounters with indifferent dental professionals, and concerns regarding the actions performed by the dentist. Consequently, a symptomatic approach is likely to lead to more invasive treatments, such as tooth extractions, which can further intensify dental fear.

The "accummulation of risk" model represents a single adverse or protective encounter connected to subsequent circumstances accumulates throughout an individual's lifespan, subsequently impacting oral health outcomes in later years [40, 45]. For instance, children with irregular dental attendance or those brought up in disadvantaged socioeconomic conditions are more prone to report dental anxiety, take up smoking, and display inadequate oral hygiene practices [53]. These elements, in turn, heighten the likelihood of experiencing dental caries and oral consequences. Despite the temporal associations delineated in longitudinal investigations, it remains conceivable that there are common predictors influencing both dental visitation patterns and oral health outcomes, such as socioeconomic standing, healthcare accessibility, and dental phobia.

Another discovery worthy of emphasis is the potential for a reciprocal relationship between oral health and dental check-up patterns. A bidirectional interaction between persistent tooth loss and long-term dental attendance both serving as indicators of Oral Health-Related Quality of Life (OHRQoL) was identified by Åstrøm et al. [37]. Previous research has delved into the influence of oral health status on dental attendance; for example, a longitudinal study among Finnish adults revealed that subpar OHRQoL resulted in irregular utilization of dental services [54]. Furthermore, a cross-sectional study involving the elderly population unearthed a favorable correlation between edentulism and uncommon dental care use.

Future research should consider two other significant covariates: dental anxiety and chronic conditions. Despite abundant evidence indicating their correlations with dental check-ups and oral health outcomes, only a few studies address dental anxiety, and chronic conditions are rarely taken into account. Moreover, there is a pressing need for longitudinal studies and empirical data from diverse settings, particularly in lower- and middle-income countries, which account for approximately 65% of the global population. These regions exhibit a higher prevalence of oral diseases and a more substantial unmet demand for dental services compared to other areas; however, they are underrepresented in research and publications, especially low-income countries. Additionally, conducting such analyses is uncommon due to the extensive follow-up period, resource constraints, and limited availability of oral health-related birth cohort studies. Enhancing regular data collection and fostering seamless data integration within the oral healthcare system across different sectors and institutions could facilitate more extensive research and comprehensive evaluations in the field of dentistry. In the realm of epidemiological research, the potential implications of big data linkage should be acknowledged.

5.2 Establishing proper oral hygiene routines at an early age

Developing proper oral hygiene routines during early childhood is vital for preventing oral diseases such as gingivitis and periodontitis, which are linked to systemic health issues. The prevention of plaque accumulation through regular and thorough mechanical plaque removal, such as toothbrushing and interdental cleaning, plays a critical role in maintaining periodontal health. Consistent oral hygiene practices, when established early, help reduce the prevalence of chronic oral diseases later in life and improve overall dental health outcomes. The most effective oral hygiene measures for children involve systematic toothbrushing using fluoride toothpaste twice daily, ideally for 2 minutes per session. This not only prevents caries but also reduces plaque, a precursor to gingival inflammation and periodontal diseases. For interdental cleaning, devices such as interdental brushes are more effective than flossing, especially as children grow older. Encouraging proper brushing techniques early ensures long-term adherence to good oral hygiene habits. Power toothbrushes, though not essential, can be especially effective for children, as they provide enhanced plaque removal compared to manual toothbrushes. Combining the use of such tools with parental supervision or interactive technologies that provide feedback can enhance the effectiveness of brushing routines. Saliva, dietary choices, and behavioral factors also play complementary roles in oral hygiene. Chewing fibrous foods and maintaining adequate hydration contribute to the natural cleansing of oral tissues, although they are insufficient substitutes for proper mechanical cleaning. Lastly, oral health education tailored to individual needs and preferences is essential. Early involvement of parents and caregivers in teaching and monitoring children's oral hygiene practices fosters consistency and reduces the risk of developing oral diseases. Regular dental visits to reinforce these practices and provide professional preventive care further support the establishment of lifelong oral health routines [55].

5.3 Collaboration between parents, pediatricians, and dental professionals

The importance of interdisciplinarity in professions addressing the needs of young children has been widely recognized in the literature. Health care for children in their first year of life should involve collaborative efforts, with oral health guidance being a shared responsibility among all professionals interacting with the child, rather than solely the dentist. Qualified members of health teams can effectively educate parents or guardians about proper oral care during early childhood. In this context, pediatricians play a pivotal role in promoting oral health. As they engage with parents or guardians shortly after a baby's birth and continue to monitor the child's growth and development from birth to age three, pediatricians are well-positioned to provide guidance on habits, behaviors, and actions that support a healthy lifestyle, including maintaining good oral hygiene [56].

6. Leveraging community support and collaboration

6.1 The role of schools and educators in promoting oral health

Good oral health is essential for overall well-being, as dental issues such as cavities, gum disease, and tooth decay can lead to significant discomfort, pain, and, if untreated, serious health complications. Poor oral health can also impact a child's ability to eat, speak, and focus in school, negatively affecting academic performance and social interactions. Schools are uniquely positioned to instill lifelong oral hygiene habits, empowering students to maintain healthy smiles and thrive academically and socially. Oral health significantly influences both academic performance and overall well-being. Studies have shown that poor oral health is associated with decreased school attendance and performance. Therefore, implementing school-based oral health initiatives is critical for improving students' overall health and quality of life These programs not only educate students about proper oral hygiene but also emphasize the importance of parental involvement in ensuring their success.

Integrating oral health education into school curricula has proven effective in enhancing students' oral hygiene practices and preventing dental issues. Establishing an "oral health-promoting school" environment offers a holistic approach to improving oral health behaviors and reducing dental caries among children. Such efforts can also address disparities in oral health outcomes through collaborative partnerships between schools and community organizations. Educators play a pivotal role in raising oral health awareness. Enhancing teachers' knowledge and attitudes about oral health is crucial for effectively delivering oral health education to students. Leveraging teachers to deliver oral health programs has been shown to improve students' oral hygiene behaviors in a cost-effective and scalable manner. School nurses are equally essential in providing preventive oral health services and breaking down barriers to care. Their involvement in school-based oral health initiatives has been instrumental in improving students' oral health knowledge, practices, and attitudes. Programs targeting vulnerable populations, such as children with disabilities, through school-based or home-visit models, have successfully enhanced oral hygiene practices and reduced the prevalence of dental problems. In conclusion, promoting oral health in schools requires a comprehensive approach involving educators, parents, healthcare professionals, and community organizations. Such collaboration ensures the effective delivery of oral health education, regular dental check-ups, and the adoption of healthy habits, including balanced nutrition and fluoride use. By fostering a supportive environment, schools can help mitigate the impact of dental problems on academic outcomes, such as absenteeism, decreased concentration, and lower grades, while contributing to the overall well-being of students [57].

6.2 Community outreach programs targeting at-risk populations

Effective public health interventions are crucial in addressing dental caries, particularly among young children. Several programs have been identified as both clinically and cost-effective in reducing caries levels in children under the age of five. These interventions not only improve oral health outcomes but also demonstrate significant societal benefits, such as increased school attendance and reduced healthcare costs. Supervised toothbrushing programs implemented in schools and nurseries create a supportive environment for establishing good oral hygiene practices. These habits can be replicated at home, leading to population-level reductions in dental caries. For example, data suggest that after 5 years of supervised toothbrushing, significant improvements in school attendance and oral health outcomes are observed, with thousands of additional school days gained among participating children. Mailing free toothbrushes and toothpaste directly to households encourages parents to adopt and sustain proper oral health routines for their children. These programs help address barriers to access and uptake by providing essential tools and resources. Health workers can play a pivotal role in reinforcing these efforts through community engagement and education. Fluoride varnish programs, delivered by trained dental professionals outside of traditional dental settings, have proven to be highly effective in reducing caries levels, particularly in high-risk areas. These interventions are typically administered at least twice a year and require coordination with dental practices to ensure proper fluoride dosage and follow-up care. Targeted fluoride varnish applications provide a practical approach to reaching underserved or vulnerable populations. Water fluoridation is a systemic, community-based intervention that provides fluoride without requiring changes in individual behavior. Research shows that it can reduce caries prevalence by up to 50%, with children in fluoridated areas experiencing significantly lower rates of dental caries and fewer hospital admissions compared to those in non-fluoridated regions. This intervention is not only cost-effective but also helps to reduce social inequalities in oral health outcomes. Although water fluoridation is occasionally a topic of public debate, the balance of scientific evidence supports its safety and effectiveness as a public health measure. Studies have consistently demonstrated its significant benefits in improving dental health, particularly in communities with limited access to dental care or preventive services. These community outreach programs provide scalable and effective solutions to improve oral health in at-risk populations, reducing the burden of dental diseases and contributing to overall societal well-being [58].

6.3 Interdisciplinary collaboration for better health outcomes

Interdisciplinary collaboration is essential for addressing widespread issues like early childhood caries (ECC) and improving overall health outcomes. Coordinated efforts among dental, medical, public health professionals, educators, and policymakers can bridge care gaps, expand access, and promote health equity in underserved populations. Interprofessional education (IPE) fosters collaboration by training health professionals from various disciplines to work together effectively. Programs integrating dental and medical providers have shown success in improving oral health knowledge and care delivery, emphasizing the need for teamwork to address ECC prevention and treatment comprehensively. Community health workers (CHWs) with oral health training play a vital role in connecting underserved populations to dental care. Their cultural and linguistic familiarity helps build trust, increase service use, and provide preventive care in hard-to-reach areas. Additionally, technological innovations like tele-dentistry and virtual dental homes extend care to remote populations, enabling community-based providers to deliver preventive services and refer complex cases to specialists. Efforts must also address systemic factors affecting oral health, such as policies to reduce sugar consumption and improve access to education about oral hygiene. Collaboration between public health professionals, educators, and community advocates is vital to promoting preventive care and tackling structural barriers to access. By fostering interdisciplinary partnerships, healthcare systems can better integrate oral health into broader health initiatives, reduce disparities, and improve health outcomes for children and underserved populations globally [59].

7. Innovative interventions for improved oral health

7.1 Comprehensive oral health interventions to prevent early childhood caries (ECC)

Evidence on the effectiveness of early interventions to prevent ECC is inconclusive and well-designed studies that include more children are needed [60, 61].

This implies that research should consider that even uncomplicated behavioral interventions for the prevention of Early Childhood Caries (ECC) are frequently impacted by intricate interactions of individual traits, societal determinants, healthcare delivery systems, and the interventions themselves, necessitating them to be regarded as sophisticated health interventions. A Comprehensive Health Intervention (CHI) is characterized by multiple components (intervention complexity), complicated/multiple causal pathways, feedback loops, synergies, mediators, and moderators of effect (pathway complexity) [62]. In addition, they may exhibit population complexity (targeting multiple participants, groups, or organizational levels), implementation intricacy (necessitating multifaceted adoption, uptake, or integration strategies), and/or contextual intricacy (operating in a dynamic multidimensional environment) [62]. Due to the intricate interactions of mechanisms and components, conflicting outcomes often arise when a CHI is implemented in diverse scenarios. Consequently, assessing the impacts of CHI's proves to be a formidable task, necessitating a nuanced and comprehensive approach. Recent systematic reviews in this field have encompassed studies that align with the CHI definition, yet they have adopted a simplistic, reductionist approach that primarily emphasizes efficacy without delving into the intricate dynamics of the intervention [60, 61]. Instead of focusing only on the effectiveness of interventions, more emphasis should be placed on "how," "for whom," and "under what conditions an intervention can work" [62]. For those considering adopting interventions, it is crucial to have detailed information on the feasibility of the intervention, which components are most likely to be effective in their specific context, and the associated costs. This comprehensive understanding is necessary to ensure successful implementation and maximize the impact of interventions in preventing ECC [62].

While dental caries is highly preventable with twice-daily toothbrushing using fluoridated toothpaste and limited sugar intake between main meals, compliance with these measures still requires much perseverance and endurance from parents. Noncompliance is often associated with a lack of parental awareness regarding their role in preventing Early Childhood Caries (ECC), a persistent misconception that primary teeth hold no significance for future oral health, conflicts of authority with the child, and fatigue experienced by both parents and their children [63, 64]. As with many behavior-related diseases, dental caries shows marked socioeconomic disparities in all age groups [65, 66]. Dental caries can be effectively prevented through regular toothbrushing with fluoridated toothpaste and controlling sugar intake, still the challenge lies in parental compliance with these measures. Parents often face obstacles such as a lack of awareness regarding their role in preventing Early Childhood Caries (ECC), disregarding the importance of primary teeth for long-term oral health, power struggles with their children, and fatigue both in themselves and their little ones. These factors contribute to noncompliance and increase the risk of dental caries development. Dental caries is not solely a dental concern; it also mirrors socioeconomic disparities across various age groups. For instance, children from lower socioeconomic backgrounds may encounter restricted access to dental care, resulting in a higher prevalence of dental caries in comparison with their more affluent counterparts. Mitigating these disparities necessitates not only individual endeavors but also systemic transformations to guarantee equitable oral health outcomes for all. By comprehending the fundamental causes of noncompliance and socioeconomic influences on dental health, interventions can be customized to effectively tackle the multifaceted nature of dental caries.

Life-course epidemiology stresses the pivotal role that early childhood plays in shaping optimal oral health outcomes [40, 67]. For instance, studies have shown that children who establish good oral hygiene practices from a young age are more likely to maintain healthy teeth and gums throughout their lives. It is crucial for parents to not only understand the importance of oral hygiene but also to actively engage in teaching and modeling these behaviors for their children [40]. By introducing children to proper brushing techniques and regular dental check-ups early on, parents can set a strong foundation for lifelong oral health. One key recommendation that emerges from understanding the significance of caries prevention in early childhood is the need for children to have their first dental assessment before they turn 1-year-old. This early intervention allows dental professionals to identify any potential issues and provide guidance on preventive measures. However, a common challenge arises from the lack of emphasis placed on oral health promotion by medical and nursing personnel, who may prioritize other aspects of child well-being over dental care [68]. This highlights the importance of integrating oral health education and services into overall pediatric healthcare practices. Even when children do receive regular dental care, the effectiveness of these interventions may be limited by the absence of evidence-based practices for preventive oral care from the time the first tooth emerges [61]. For example, implementing fluoride treatments or dental sealants can significantly reduce the risk of cavities in young children. Addressing this gap requires a dual approach: engaging both young children and their caregivers in oral health practices and developing effective preventive services to target behavioral risk factors associated with poor oral health outcomes.

In conclusion, the prevention of poor oral health in early childhood necessitates a comprehensive strategy that involves early education, regular dental assessments, evidence-based interventions, and continuous oral health advocacy. By addressing these key areas, we can work toward ensuring that children start their lives with strong oral health foundations that will benefit them well into the future.

7.2 Digital dentistry: The way forward in oral health education

The rapid advancements in digital technology have revolutionized education, significantly altering how knowledge is imparted, acquired, and applied. The integration of digital tools such as mobile devices, smartboards, virtual laboratories, and simulations has made education more engaging, interactive, and accessible to a broader audience. These innovations have bridged gaps in traditional learning environments, offering students the opportunity to learn at their own pace while fostering creativity, collaboration, and critical thinking. The adoption of digital classrooms, enhanced by internet connectivity and advanced learning platforms, has transformed teaching methodologies, making them more dynamic and inclusive. The COVID-19 pandemic further accelerated the institutionalization of digital technologies in education. Remote learning tools became indispensable, ensuring the continuity of education globally. Tools like online learning management systems (LMS), video conferencing, and cloud-based platforms facilitated virtual classrooms and allowed teachers and students to connect in real time or asynchronously. These technologies enhanced the flexibility of education, supporting personalized learning approaches and addressing the diverse needs of students. In addition to accessibility, digital technologies have redefined the role of teachers, shifting their focus from traditional instruction to guiding students in navigating and utilizing digital resources effectively. This shift aligns with the United Nations' Sustainable Development Goals (SDGs), particularly the commitment to providing equitable and inclusive quality education for all. Innovations such as gamification, augmented reality (AR), and virtual reality (VR) are proving invaluable in fostering engagement and motivation, making complex concepts more comprehensible and interactive for learners of all ages [69].

The rapid advancements in digital technology have revolutionized dentistry, enabling more effective and efficient preventive care. Modern tools such as augmented reality (AR), virtual reality (VR), tele-dentistry, additive manufacturing, and artificial intelligence (AI) are enhancing patient care, improving clinical outcomes, and facilitating accessibility to oral health services. AR and VR provide immersive, interactive simulations that enhance both clinical practice and education. AR integrates digital overlays into real-world scenarios, while VR creates fully immersive virtual environments. These technologies are particularly effective in prosthodontics, oral and maxillofacial surgery, and dental education. They allow practitioners to pre-plan treatments, such as denture design or surgical templates, ensuring precision and reducing errors. In education, AR/VR enables students to practice complex procedures, such as implant placement, in a risk-free environment, improving their skills and confidence. Tele-dentistry bridges the gap in care for patients in remote or underserved areas, offering virtual consultations and remote monitoring. It reduces the need for in-person visits, facilitates early diagnosis of conditions like caries and oral cancer, and empowers patients to manage oral health at home. By integrating tele-dentistry with real-time data sharing, healthcare professionals can collaborate more effectively to deliver comprehensive, patient-centered care, while minimizing costs and travel burdens. AI is playing a pivotal role in diagnostics and treatment planning. Advanced machine learning algorithms are being used for automated detection of dental caries, periodontal disease, and oral tumors through radiographic analysis. In restorative dentistry, AI enhances the accuracy of caries detection and predicts treatment outcomes. AI also supports orthodontic treatment planning by optimizing aligner designs and tooth movement strategies. In endodontics, AI aids in diagnosing periapical pathologies and assessing the complexity of root canal treatments. These capabilities reduce human error, improve efficiency, and enable personalized care [70]. The integration of teledentistry and digital tools into preventive dental care has significantly improved access, education, and monitoring, particularly for pediatric patients and underserved populations. Teledentistry, through technologies such as m-Health apps, intraoral cameras, and smartphones, facilitates remote diagnosis, behavioral guidance, and oral health education, addressing disparities in access to care. These tools empower patients and families by promoting oral hygiene, reducing dental anxiety, and providing resources for managing dental conditions remotely. Features such as educational games, animations, and multimedia in apps are particularly effective in engaging children and fostering better oral health habits. Remote diagnosis using digital imaging allows for prioritizing urgent cases, connecting general dentists with specialists, and enabling collaborative, multidisciplinary treatment planning. Telemonitoring has proven beneficial in orthodontics, where many emergencies can be managed remotely, reducing stress for families and saving time for practitioners. However, certain limitations, such as the need for high-quality images and reliable internet access, highlight the importance of refining these technologies and ensuring equitable availability [71]. Together, these innovations complement advanced tools like AR/VR and AI, creating a holistic approach to improving preventive care and patient outcomes in dentistry. As children grow older, mobile health (mHealth) apps present new opportunities to enhance pediatric oral hygiene through innovative features like gamification. Gamification, which incorporates elements such as badges, levels, and leaderboards, is designed to boost engagement and encourage desired behaviors by making tasks more enjoyable and interactive. Widely used in other health domains, such as asthma management, fitness, chronic disease care, smoking cessation, and health promotion, gamification also holds significant promise for dentistry. These features can support evidence-based dentistry (EBD) by motivating children to maintain consistent oral self-care habits. Integrating gamification into mHealth apps complements existing approaches, such as educational games and animations, creating a dynamic and engaging way to foster better oral hygiene and long-term health behaviors in children [72].

8. Conclusion

Children's oral health is a critical aspect of overall well-being, profoundly influenced by contemporary risk factors, parental education, and preventive care strategies. This chapter highlights the multifaceted challenges and opportunities in promoting oral health among children in the modern context. Key factors shaping children's oral health include dietary habits, sedentary lifestyles, and environmental influences. The consumption of sugary and acidic foods, combined with increasingly sedentary behaviors, has exacerbated the prevalence of dental caries and related systemic health issues. Addressing these challenges requires a shift toward balanced diets and active lifestyles, supported by community-driven and policy-led initiatives. Environmental determinants, such as access to fluoridated water and the impact of climate change, further underscore the need for systemic and equitable public health interventions. Parental education emerges as a cornerstone for improving children's oral health outcomes. Parents' awareness and behaviors significantly influence their children's oral hygiene practices, dietary choices, and access to preventive care. Educating parents about effective oral health habits and addressing barriers faced by those with limited education are vital steps toward reducing disparities. Collaborative efforts among parents, healthcare providers, and educators can foster a supportive environment for instilling lifelong oral hygiene habits in children. Preventive care remains the foundation of oral health. Regular dental check-ups, early intervention, and the establishment of proper hygiene routines from a young age are essential for mitigating long-term oral and systemic health issues. Schools, healthcare systems, and community programs play a pivotal role in implementing accessible and cost-effective interventions, such as fluoride varnish programs, supervised brushing, and educational campaigns.

Looking ahead, the vision for children's oral health must integrate these modern approaches into a cohesive framework that prioritizes prevention, education, and equity. By fostering interdisciplinary collaboration and empowering families and communities, we can create sustainable solutions that address both current challenges and future needs. Ensuring that all children, regardless of socioeconomic status or geographic location, have access to quality oral health care and education will pave the way for healthier generations and a brighter, more equitable future.

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Conflict of interest

The authors declare no conflict of interest.

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Section 3

Oral Pathology

Chapter 7

Clinico-Statistical Study of Oral Lichen Planus and Lichenoid Dysplasia

Kazumasa Mori and Ari Matsumoto

Abstract

Here, we report a clinical study involving 31 patients (10 men and 21 women, with a male/female ratio of 1:2.1) who received a histopathological diagnosis of lichenoid dysplasia. The peak of age distribution was around 60 years for both male and female patients. The most frequently affected site was the buccal mucosa, and the most frequently observed lesions were reticular (18 cases, 58.1%), erosive (16 cases, 51.6%), and atrophic (18 cases, 58.1%). The most frequent clinical diagnoses before pathological examination at the time of the first visit were oral lichen planus. But tumours, leucoplakia, and erythroplakia were suspected in 16 cases (51.4%) (clinical diagnosis other than OLP). Chief complaints during the first visit were stinging and burning sensation. The cohort also included asymptomatic patients who wished for closer examination. The most frequent histopathological findings of dysplasia were mild, followed by moderate. Two cases (6.5%) became cancerous during follow-up.

Keywords: lichenoid dysplasia, oral lichen planus, oral epithelial dysplasia, clinico-statistical study

1. Introduction

Oral lichenoid conditions (OLC) include oral lichen planus (OLP), oral lichenoid lesions (OLL), and oral lichenoid dysplasia (OLD), which are classified by the World Health Organisation (WHO) as oral potentially malignant disorders (OPMDs) in 2017 and in the fifth edition of the WHO classification in 2022: Oral Potentially Malignant Disorders (OPMDs) [1–3]. Clinical criteria include the appearance of bilateral reticulated lesions and six disease types: erosive, atrophic, mottled, popular, and blistering [4]. Histopathological criteria are defined as the presence of an inflammatory infiltrate of lymphocytes in the form of bands in the subepithelial connective tissue, oedematous degeneration of the basal layer, and absence of epithelial dysplasia, with typical lichen planus being defined when clinical and histopathological criteria are met [5–7]. However, OLL and OLD are not detailed in the WHO tumour classification [2, 3]. OLL can occur unilaterally or bilaterally and includes dental restorative materials, drugs, systemic lupus erythematosus, and graft-versus-host disease (GVHD) (**Figure 1a**, **b**) [8, 9]. OLD was first described by Krutchkoff and Ersenberg and was defined as lichen planus when the clinical presentation and histopathological criteria

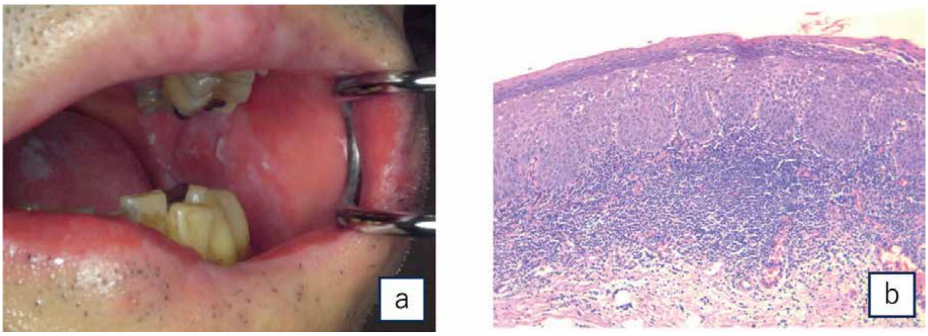

Figure 1.
Case of GVHD with malignant transformation of OLD into OSSC. a: Portrait of the oral cavity at first medical examination of initial diagnosis. b: Histopathological findings from initial biopsy (HE staining) x 100. Severe oral lichenoid dysplasia was diagnosed. Some carcinoma in situ are observed.

are met [10]. Although OLP, OLL, and OLD differ in aetiology, pathogenesis, and biological behaviour, their clinical presentations and histopathological findings are similar [11]. The exact distinction between OLC has not yet been established, and a method for grading OLC is desired [12].

Several attempts to investigate the histopathological malignant transformation of OLC have been reported. They examined the differential expression of Ki-67 and p53 in OLC and found that their expression differed among OLP, OLL, and OLD [13]. A particularly interesting report is the investigation of macrophage involvement in OLC [14, 15]. The authors closely examined the differential expression of OED in oral squamous cell carcinoma (OSCC), focusing on carcinoma invasiveness, and reported that CD163 macrophages were upregulated with increasing degrees of dysplasia [16]. The expression of OLC on CD163 macrophages was compared and found to vary according to their localisation in carcinogenesis and the intensity of the immune response. This may serve as a noteworthy indicator of malignant transformation [17]. Silver nucleolar regions have also been studied to diagnose OEDs [18]. They reported that counting the number of AgNORs does not distinguish individual dysplastic lesions but that an increase in their number can easily distinguish OLC from OLD and may be related to the cellular activity of OLD. The molecular profiles of cases diagnosed with OLP, OLD, and OED were investigated, and OLD as a distinct and independent pathology was investigated using RNA sequencing. The results showed differential expression of macrophages M1, M2, CD8+ T cells, and regulatory T cells among OLP, OLD, and OED. This suggests that the immune cell populations of OLP and OLD may be similar but different from those of OED [19]. The authors also concluded that OLD lesions had a significantly higher risk of malignant transformation than OLP lesions (6.8% for OLD and 0.5% for OLP) [20]. OLP have a high risk of malignant transformation. It concluded that OLP had a malignant transformation rate of 1.43% (95% confidence interval [CI] = 1.09–1.80), OLL had 1.38% (95%CI = 0.16–3.38), and OLP with dysplasia 5.13% (95%CI = 1.90–9.45). There was no significant difference between OLL and OLP; however, there was a significant difference between OLP and OLP with dysplasia, indicating the presence of epithelial dysplasia as a factor in malignant transformation. They also found that tobacco use, alcohol consumption, hepatitis C, and the presence of atrophic or erosive lesions during clinical presentation increased the risk of malignant transformation of OLP [21].

Treatment methods vary and are largely divided into oral care, local treatment, and systemic treatment, each of which has been reported to be effective [22]. In oral care, poor oral hygiene can lead to secondary infection of oral commensal bacteria, which can be a factor in the onset or exacerbation of OLC. Adequate oral cleaning is, therefore, crucial as an initial treatment. OLC can be expected to improve if triggers and aggravating factors are identified and removed. Local treatments include mouthwashes, topical steroids, immunosuppressive drugs, and surgical resection. Systemic therapies include oral steroids, herbal medicines, vitamins, immunomodulators, and psychotropic drugs. The goal of all treatments is to prevent the development of cancer and completely cure the disease. However, many clinical case studies and their effectiveness are awaited.

The definition and findings of OLC, as well as the search for cases of cancer transformation, remain controversial. It is important to establish clear definitions, diagnostic criteria, and precise treatment methods based on clinicopathological studies of the disease.

OLP and OLD appear to include dysplasia in OLC, but there is no clear evidence supporting this in terms of histology or pathogenetic mechanism of action. However, there are significant differences in malignant transformation between the two conditions, which require further clinical and histopathological investigation. Therefore, we would like to discuss the clinical findings of cases histopathologically diagnosed as OLD in our department from 1990 to 2020, focusing on comparison with OLP cases [23] and other reports.

2. Material and methods

About 31 patients who visited the Department of Oral and Maxillofacial Surgery, Meikai University Hospital, Meikai University School of Dentistry, during the 31-year period from 1990 to 2020, and were followed up for more than 3 years after histopathological diagnosis of OLD on biopsy were included in this study to investigate their clinical findings. The following information was collected: age, sex, chief complaint, site of origin, clinical type, clinical diagnosis before initial pathological examination, history, histopathological dysplasia, and carcinogenesis. About 100 patients who visited our department and were histopathologically diagnosed as OLP in 15 years between 2006 and 2020 were used as comparators for OLD [23]. The clinical forms of OLP were retrospectively examined in 72 cases whose photographs were stored in the medical records. Histopathological studies were performed on the biopsy specimens from each case, and the findings were determined based on the haematoxylin and eosin staining results. Three certified oral pathologists made the pathological diagnoses. The study was conducted with the consent of the Ethics Committee of the Meikai University School of Dentistry (approval no. A-1424).

3. Results

1. Sex differences and age distribution (**Figure 2a** and **b**)

The male OLD cases were 10/31 (32.3%), and the female OLD cases were 21/31 (67.7%), with a male to female ratio of 1:2.1. The most common age group was 60s for both men and women, followed by 70s for both men and women. The mean age was 61.5 years (**Figure 2a**). About 26/100 (26.0%) OLP cases were male and 74/100 (74.0%) were female, with a male to female ratio of 1:2.8. The most common age group was 60s for both men and women, followed by men in their 50s and women in their 70s. The mean age was 58.2 years for males and 58.0 years for females (**Figure 2b**).

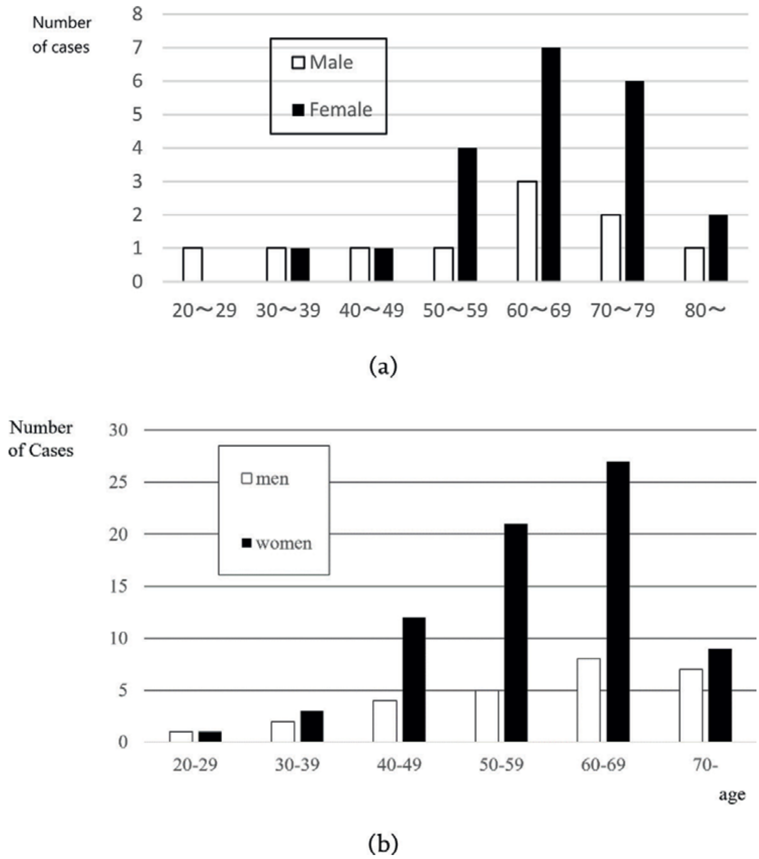

Figure 2.
a. Distribution of LD by sex and age. A clinical study on 31 patients (10 males, 21 females; the male/female ratio was 1:2.1) who were histopathological diagnosised as lichenoid dysplasia (LD). The peak of age distribution was for both male and female was in their sixties. b. Distribution of OLP by sex and age. A total of 100 patients (26 men and 74 women, 1: 2.85) with histopathological diagnosis of oral lichen planus (OLP) in our department were clinically evaluated. Oral lichenoid lesion (OLL) and lichenoid dysplasia (LD) were excluded.

2. Chief complaints (**Tables 1** and **2**).

The most common complaint in OLD cases was stinging/burn (11/31, 35.5%), followed by a desire for closer examination (9/31, 29.0%); in OLP cases, the most common complaint was stinging/burn (29.0%, 29/100), followed by a desire for closer examination (24/100, 24.0%). Contact pain was present in 18/100 (18.0%), and pain (burning and contact pain) was the main complaint in 47/100 (47.0%) of cases.

3. Site of occurrence (**Tables 3** and **4**).

Of the OLD cases, the total number of lesions was 50, with an average of 1.61 lesions per case. The most common site of occurrence was the buccal mucosa with 34/50 lesions (68.0%). OLP cases had a total of 188 lesions out of 100 cases, with a mean of 1.88 lesions per case. The most common site of occurrence was the buccal mucosa with 130/188 lesions (69.1%), with no difference between right and left sides. The mandibular gingiva was the next most common site with 41/188 gingival lesions (21.8%).

Chief complaint of LD		
Chief complaint	**Number of cases**	**(%)**
Haphalgesia	5	16.1
Burning	11	35.5
Sense of discomfort	3	9.68
Crude feeling	3	9.68
Hope for scrutiny	9	29
Multiple symptoms	0	0
Total	31	100

Table 1.
Chief complaint of LD.

Chief complaint of OLP		
Chief complaint	**Number of cases**	**(%)**
Haphalgesia	18	18.0
Burning	29	29.0
Sense of discomfort	10	10.0
Crude feeling	4	4.0
Hope for scrutiny	24	24.0
Multiple symptoms	15	15.0
Total	100	100

Table 2.
Chief complaint of OLP.

	Bucal		**Tongue**	**Gingiva**		**Lip**	**Floor of cavity**	
	Left	**Right**		**Upper**	**Lower**			**Total**
Number of lesions	17	17	7	3	4	1	1	50
Total	34		7	7		1	1	
%	68.0		14.0	14.0		2.0	2.0	

Table 3.
Location of LD.

	Bucal		**Tongue**	**Gingiva**		**Lip**		**Palate**	
	Left	**Right**		**Upper**	**Lower**	**Upper**	**Lower**		**Total**
Number of lesions	66	64	11	10	31	2	3	1	188
Total	130		11	41		5		1	
%	69.1		5.9	21.8		2.7		0.5	

Table 4.
Location of OLP.

4. Clinical types (**Tables 5-8**).

According to Andreasen's classification [4], the lesions were classified into six types: reticulate, erosive, atrophic, macular, papular and bullous. Of the six lesion

Clinical visual examination type		Number of cases	(%)
Monotypic 7 (22.6%)	reticular	3	9.7
	erosive	0	0
	atrophic	2	6.5
	plaque	2	6.5
	papular	0	0
	bulla	0	0
Mixed lesions 24 (77.4%)	reticular-atrophic	5	16.1
	erosive-atrophic	4	12.9
	reticular-erosive	4	12.9
	erosive-atrophic-plaque	3	9.7
	reticular-erosive-atrophic	3	9.7
	reticular-atrophic	2	6.5
	reticular-erosive-atrophic	1	3.2
	reticular-plaque	1	3.2
	atrophic-plaque	1	3.2
Total		31	

Table 5.
Type of LD.

Clinical visual examination type		Number of cases	(%)
Monotypic 32 (44.4%)	reticular	28	38.9
	erosive	0	0
	atrophic	1	1.4
	plaque	3	4.2
	papular	0	0
	bulla	0	0
Mixed lesions 40 (55.6%)	reticular-erosive	14	19.4
	reticular-erosive-atrophic	10	13.9
	reticular-atrophic	5	6.9
	erosive-atrophic-plaque	3	4.2
	erosive-atrophic	3	4.2
	erosive-plaque	3	4.2
	atrophic-plaque	2	2.8
Total		72	

Table 6.
Type of OLP.

	Reticular (+)	Reticular (−)	Total
LD	17(54.8%)	14(45.2%)	31
OLP	84(84.0%)	16(16.0%)	100

Table 7.
Presence of reticular form of type.

	Atrophic (+)	Atrophic (−)	Total
LD	15(48.4%)	16(51.6%)	31
OLP	35(35.0%)	65(65.0%)	100

Table 8.
Presence of atrophic form of type.

types, those with a single lesion were classified as single lesion type and those with two or more lesions of the same type were classified as mixed type. About 7/31 (22.6%) of the OLD cases were of single lesion type and 24/31 (77.1%) were of mixed type. The most common type of OLD was atrophic in 19/31 (61.3%). (**Tables 5** and **6**). The reticulocystic type, which is relatively easy to identify in the classification of pathological types, was present in 17/31 (54.8%), while 14/31 (45.2%) did not present with reticulocystic type (**Table 7**). Erosions and ulcerations (erosive type) were observed in 15/31 (48.4%) and 16/31 (51.6%) of the cases, respectively (**Table 8**). OLP cases were 32/72 (44.4%) monomorphic, and 40/72 (55.6%) were mixed (**Table 8**). The most common clinical presentation was a single reticular type in 28/72 (38.9%) cases (**Tables 5** and **6**). Reticular (single reticular type + mixed reticular type) was present in 57/72 cases (79.2%), while 15/72 cases (20.8%) did not present with reticular type. Erosions and ulcerations (erosive type) were present in 33/72 (45.8%) of cases. Atrophic cases were 24/72 (33.3%).

5. Clinical diagnosis before histopathological examination at initial presentation (**Tables 9** and **10**).

About 15/31 (48.4%) OLD patients had OLP as the clinical diagnosis before histopathological examination at the first visit. On the other hand, 16/31 (51.6%) had a clinical diagnosis other than OLP: 10/31 had tumours, 4/31 had leukaemia, and 2 had erythroplakia. About 89/100 (89.0%) of OLP cases had OLP as the clinical diagnosis before histopathological examination at the first visit. On the other hand, 11/100 cases (11.0%) had a clinical diagnosis other than OLP: 6/100 cases (6.0%) had tumour, 4/100 cases (4.0%) had leucoplakia, and 1/100 cases (1.0%) had nicotinic stomatitis.

Clinical diagnosis before biopsy	Cases	%
OLP	15	48.4
Tumor	10	32.3
Leukoplakia	4	12.9
Erythroplakia	2	6.5

Table 9.
Clinical diagnosis before biopsy whose definitive diagnosis is LD.

Clinical diagnosis before biopsy	Cases	%
OLP	89	89.0
Tumor	6	6.0
Leukoplakia	4	4.0
Nicotine stomatitis	1	1.0

Table 10.
Clinical diagnosis before biopsy whose definitive diagnosis is OLP.

6. Histopathological dysplasia (**Table 11**).

The histopathological examination showed that 17/31 (54.8%) had mild dysplasia, followed by moderate 7/31 (22.6%), mild to moderate 3/31 (9.7%), and severe 3/31 (9.7%). The number of cases of carcinomatosis is 7.

7. Cancerous cases (**Figure 3a** and **4a–d**).

About 2/31 (6.5%) cases of malignant transformation were observed in OLD patients. No cases of carcinoma were found in OLP cases. The first case was a 59-year-old woman who presented with mixed reticular, papular and atrophic findings from the right buccal mucosa to the gingiva and was diagnosed as OLD (moderate

Dysplasia	Case
Mild	17
Mild to moderate	3
Moderate	7
Moderate to severe	1
Severe	3

Table 11.
Degree of dysplasia.

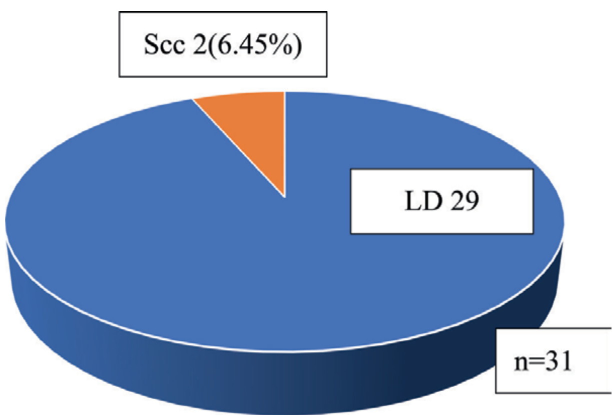

Figure 3.
Malignant transformation cases. Two cases (6.5%) became cancerous during follow-up.

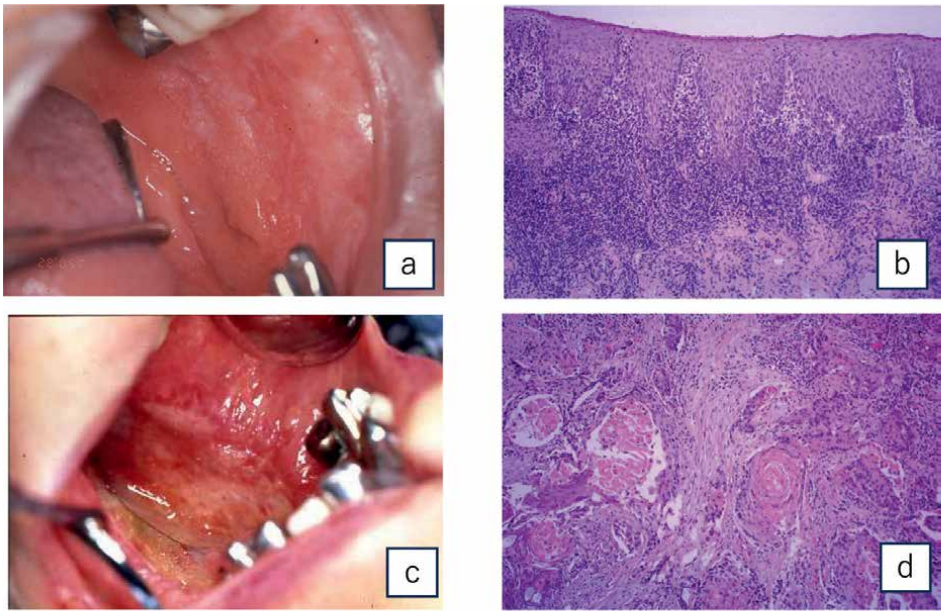

Figure 4.
Cases of malignant transformation of OLD into OSSC. a: Portrait of the oral cavity at the time of initial diagnosis. b: Histopathological findings from initial biopsy (HE staining) x 100. Mild to moderate oral lichenoid dysplasia was diagnosed. c: Intraoral photographs after 5 years. d: Histopathological findings from biopsies at 5 years (HE staining) x 100. Diagnosed as highly differentiated squamous cell carcinoma.

dysplasia) after histopathological examination. The second case was a 60-year-old woman who presented with mixed reticular, erosive and atrophic findings in the left buccal mucosa and was diagnosed as OLD (mild to moderate dysplasia) after histopathological examination. About 5 years later, she was found to have squamous cell carcinoma (SCCA) (**Figure 4a**–**d**).

4. Discussion

In 1985, Krutchkoff and Eisenberg proposed diagnostic criteria for the diagnosis of OLD as a disease with dysplasia with lichenoid features [10] and described it as one of the lichenoid lesions [24]. Kumar et al. [25] described the aetiology of OLD as a dysplastic change of lichen planus, rather than a dysplastic change of lichen planus. The aetiology of OLP and OLD is completely different, with OLP being a mucocutaneous disease resulting from a cellular immune mechanism with T-cell infiltration induced by antigens expressed by keratinocytes due to factors triggering the lesions. On the other hand, it has been reported that LD may be caused by an immune surveillance mechanism against atypical epithelial cells [26]. However, even in recent years, there is still much debate regarding the malignant transformation of OLP, OLL and LD, as well as the aetiology of the disease [27]. In this article, the clinical manifestations of LD in our department were compared with those of OLP in our department and other reported papers, and the differences in clinical findings between LD and OLP were discussed.

4.1 Sex differences and age distribution

Regarding gender and age of occurrence, LD in our department was 32.3% male and 67.7% female, with a sex ratio of 1:2.1; for OLP, the incidence in our department was 26.0% male and 74.0% female, with a sex ratio of 1:2.8; according to a systematic review in 2020, the incidence rate was 1.01%, with an incidence rate of and the incidence rate increases from the age of 40 years [28]. A comparison of the incidence of LD and OLP in our department showed that both tended to predominantly occur in women, but the difference between men and women was slightly less in LD. The age distribution of LD cases in our department showed that the most frequent age group was 60 for both sexes, followed by 70 for both sexes, with a mean age of 61.5 years. On the other hand, the age distribution of OLP cases was most common in the 60s for both sexes, followed by females in their 50s and males in their 70s, with a mean age of 58.0 years. These results suggest that LD tends to be slightly more common in the elderly than OLP. A comparison of OLP cases in which OLP and OSCC occurred reported that the age at occurrence was approximately 10 years older than in OLP [29]. Although rare, OLP can also occur in children. However, the occurrence of OLD has not been reported [30, 31].

4.2 Chief complaint

The main complaint of LD patients in our department was pain, such as burning, tingling, or contact pain, in 51.6% of cases. In our OLP, 47.0% of the patients presented with burning, tingling, or contact pain, and 24.0% of the patients presented with no complaints of discomfort, but came to our department for a thorough examination. MaCartan [32], Scully [33], and colleagues reported that 55.6% of OLP patients presented with burning sensation or pain on contact, and 44.4% presented for examination without complaints of discomfort. Other studies reported similar clinical symptoms, with the most common being a burning sensation, pain, and no symptom of roughness; OLD is unlikely to differ in clinical presentation [34].

4.3 Site of occurrence

Of the sites of occurrence of LD in our department, the total number of lesions was 50, with an average of 1.61 lesions per case, and the buccal mucosa was the predominant site in 68.0% of cases. The buccal mucosa was bilateral in 35.5% of cases and unilateral in 38.7% of cases. Al-Hashimi et al. [35] reported that OLP tended to occur on the bilateral buccal mucosa. Other sites of OLP were the tongue and gingiva, but the floor of the mouth, palate, and upper lip were considered rare [36]. Krutchkoff et al. [10] reported that, as with OLP, epithelial dysplasia occurs more frequently on the tongue and buccal mucosa. There was no difference in the site of occurrence, which also tended to occur on the buccal mucosa in our OLD cases. The tongue is the most common site of origin in cases of malignant transformation from OLP to OSCC, followed by the buccal mucosa [29]. However, the authors also noted that the mobile mucosa of the tongue and buccal mucosa were high-risk sites for OSCC, and OLD was also considered a high-risk site for malignant transformation [27].

4.4 Clinical presentation

The clinical types of LD and OLP were retrospectively typed using Andreasen's 6 classification [4] as the visual examination type, and intraoral photographs were discussed with several specialists. The results showed that there were seven monomorphic LD cases and 24 mixed LD cases, with a tendency towards mixed types, and various combinations of pathological types. The most common type of LD was atrophic in 61.3% of the cases, including both single and mixed types. Other reports have shown that epithelial dysplasia is often associated with erosive and atrophic visualisation [10, 37, 38]. On the other hand, 33.3% of cases in our department presented with the atrophic form of OLP, which tended to be significantly less common than LD. The atrophic type mainly refers to findings with a strong tendency to erythema, and biopsy should be performed in cases with a strong tendency to erythema, considering the possibility of epithelial dysplasia, even if OLP is suspected. In this study, we focused on the presence or absence of reticulocytosis and erosion/ulceration, which are relatively easy to recognise as clinical findings. Firstly, 54.8% of the patients presented with reticulocytosis in LD, and 45.2% did not. On the other hand, 79.2% of OLPs in our department showed reticulocytosis and 20.8% did not, indicating that LDs tended not to show reticulocytosis compared with OLPs. Odukoya et al. [38] reported that epithelial dysplasia was found in 42% of oral mucosal epithelia with chronic inflammation and concluded that in the epithelial dysplasia seen under the epithelium of OLPs, the degree of chronic inflammation may be related to the frequency and extent of epithelial dysplasia.

5. Name of the clinical diagnosis before pathology at the time of initial examination

In our LD, 48.3% of cases were diagnosed as OLP based on clinical diagnosis on visual examination only. The other clinical diagnoses were tumour in 32.3%, leucoplakia in 12.9%, and erythroplakia in 6.5%, and a clinical diagnosis other than OLP was made in 51.6% of cases. On the other hand, 91.0% of OLP cases were diagnosed with OLP as the clinical diagnosis before pathological examination at the time of initial presentation. This suggests that LD cases tend to have a low concordance rate between clinical and pathological diagnosis by visual examination and palpation and may present with a form of the disease that is difficult to diagnose by visual examination alone. Onofore et al. [39] described leukoplakia and OLP as 'epithelial diseases with potential malignant potential', and concluded that the clinical and histopathological diagnosis of LD and OLP may be difficult to make by visual examination alone. Onofre et al. [39], who described leukaemia and OLP as 'epithelial diseases with potential malignant potential', found a discordance rate of 24.4% between the clinical and histopathological diagnosis. In our study, there was a discrepancy between the clinical diagnosis of LD and OLP by visual examination. In particular, more than half of the patients with LD were suspected and treated for another diagnosis. Although the malignant transformation rate of OLP is low, more accurate biopsy is necessary, as described for the pathological types in Section 5.

5.1 Histopathological dysplasia

The degree of dysplasia in LD cases was classified into five categories: mild, mild to moderate, moderate, moderate to severe, and severe. The results showed that 54.8% of the cases were classified as mild. In a report by Rock et al. [27], lichenoid mucositis cases with mild/moderate (low grade dysplasia) were compared with those with lichenoid mucositis. The results were compared between mild and moderate cases. Kusama et al. [40] suggested that, in the development, proliferation, and progression of oral squamous cell carcinoma, high-grade epithelial dysplasia may involve more genetic mutations in the expression of the tumour suppressor gene p53 protein. Therefore, the degree of epithelial dysplasia should also be considered as a possible contributor to malignant transformation in LD. However, De Jong et al. [37] reported that no cases of malignant transformation were found among highly dysplastic cases of OLP. In leukaemia, advanced dysplasia is more likely to become cancerous, but in OLP and LD, the relationship between malignant transformation and the degree of dysplasia is unclear. [41, 42] Future studies are required.

6. Cancerous transformation cases

Shearston et al. [1] reported that 0.49% of OLP and 6.81% of LD cases developed SCC in 4.8 ± 0 years and 4.6 ± 2.4 years, respectively, and that a high proportion of LD cases underwent malignant transformation. In our department, 6.5% of cases of LD were found to be carcinomatous. In 1985, Krutchkoff and Eisenberg [10] reviewed papers on the carcinogenesis of OLPs and reported that the carcinogenised OLPs were cases showing malignant change (dysplasia). From this report, they concluded that OLP without dysplasia is not precancerous disease, whereas disease with dysplasia is precancerous disease. In a systematic review of past and current thinking on LD, Raj et al. [43] discussed the oversights and misunderstandings of oral epithelial dysplasia (OED) in the pathological diagnosis of OLP and concluded that the most inflammatory cells affected by this lesion A uniform diagnosis based on the presence of OED and the clinical presentation of OLP, OLL, and LD is a future challenge. It is currently being discussed that OLP, OLL and LD could be defined as OLL and LD rather than OLP if the differences between them are clarified [28, 44–46].

Yim et al. published an interesting review of the controversy between OLP and OLD [47]. They stated three possible theories regarding the relationship between dysplasia and inflammation: Theory 1: Is Inflammation a Response to dysplasia? Theory 2: Is dysplasia a response to inflammation? Theory 3: Does the OLC cause dysplasia? Regarding Theory 1, inflammatory cells may infiltrate the antigens present in dysplastic epithelia [48]. In other words, the expression of CD8+ and CD4+ T cells was comparable in OLP, but the inflammatory infiltration of OLD was increased by CD8+ T cells. The authors suggested that this is a cytotoxic function that eliminates epithelia undergoing dysplastic transformation, suggesting that this is an inflammatory response against dysplastic cells [49]. Theory 2 postulates that inflammatory cell infiltration produces oxidative stress, cytokines, and transcription factor signals, leading to the appearance of abnormal cells, DNA damage, and structural dysplasia in the epithelial layer [50]. These changes may cause dysplasia and epithelial changes that transition to cancer, leading to the malignant transformation of OLP. Regarding Theory 3, chronic exposure of the mucosa to factors such as tobacco and alcohol may cause dysplasia. Smokers are approximately twice as likely to report dysplasia, while those with dysplasia in the tongue and buccal mucosa are three times more likely to report it. Additionally, a moderate degree of dysplasia of the dysplastic epithelium is 2.3 times more likely to progress to malignancy than a mild degree of dysplasia [27].

Although OLP, OLL, and OLD have lower rates of malignant transformation than OED in leukaemia and erythroplakia, they all carry a potential risk of malignant transformation, and clinicians must devise appropriate treatment protocols. Patients presenting with OLD findings should be carefully monitored.

7. Conclusion

We have reviewed and reported on the clinical findings of cases histopathologically diagnosed as LD in our department over the past 31 years, with a focus on comparison with our OLP and other reports.

1. The sex ratio was higher in women with both OLP and OLD than in men. The occurrence age tended to be slightly higher in OLD.

2. No differences were observed in the chief complaints, with most patients presenting with a burning sensation and contact pain in both OLP and OLD cases.

3. Concerning the site of onset, both OLP and OLD cases occurred predominantly on the buccal mucosa. The buccal mucosa, together with the tongue, is a favourable site for malignancy and a high-risk site for malignant transformation.

4. Regarding disease type, patients with OLP had a higher rate of reticulated forms, whereas atrophic forms were more common in patients with OLD. No differences were observed in the occurrence of erosions or ulcerations. In cases presenting with an atrophic type with a strong tendency for erythema, biopsy is recommended, even if OLP is suspected, considering the possibility of epithelial dysplasia.

5. Regarding the concordance rate between the clinical diagnosis name and biopsy pathology diagnosis before the initial pathology examination, OLP tended to be higher, whereas OLD was lower. This suggests that cases considered OLD may present with a pathology that is difficult to determine on visual examination, and a more accurate biopsy is necessary because of the potential malperformance.

6. In many cases, the degree of dysplasia in patients with OLD was equivalent to that in many cases. In leukaemia cases, advanced dysplasia is more likely to become cancerous; however, in OLP and OLD, the relationship between malignant transformation and the degree of dysplasia is unclear and requires further investigation.

7. There were no cases of cancer transformation in OLP in our department. In contrast, 6.5% of OLD cases were found to be cancerous. It is currently being discussed that if the differences among OLP, OLL, and OLD are clarified, OPMDs may be defined as OLL or OLD rather than OLP. In the fifth edition of the WHO OPMDs in 2022, OLP remained unchanged, but OLD was added to the classification.

Conflict of interest

There are no conflicts of interest to disclose in this paper.

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Chapter 8

Corticosteroids in Oral Medicine Practice

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Abstract

Corticosteroids are one of the most useful and commonly prescribed drugs in oral medicine practice. They are hormones of the adrenal cortex with strong anti-inflammatory and immunosuppressive effects. Topical and systemic corticosteroids are used in the treatment of many diseases with oral mucosal manifestations such as oral lichen planus (OLP), pemphigus vulgaris (PV), pemphigoid, and systemic lupus erythematosus (SLE), as well as in the treatment of chemical injuries, traumatic lesions, recurrent aphthous ulcers (RAU), and many other. Rarely occurring side effects of topical steroid therapy are oral candidiasis and mucosal atrophy. Side effects occur more often with the systemic use of corticosteroids, such as adrenal insufficiency, hypertension, diabetes, infection, glaucoma, and osteoporosis. However, despite various side effects, corticosteroids still remain irreplaceable in the treatment of numerous diseases and conditions.

Keywords: corticosteroids, oral medicine, treatment, topical corticosteroids, systemic corticosteroids, oral mucosal diseases

1. Introduction

Corticosteroids are adrenal cortex hormones that have numerous physiological and pharmacological functions. The main actions of corticosteroids include maintenance of electrolytes, cardiovascular homeostasis, and functional status of skeletal muscles and nervous system [1]. The production of steroid hormones is under control of the hypothalamic-pituitary-adrenal axis. Hormones produced by the adrenal cortex are synthetic glucocorticoids, derivatives of hydrocortisone (cortisol), based on their natural chemical formula. Cortisol participates in the regulation of carbohydrate, fat, and protein metabolism and also plays a role in the body's response to a stressful situation [1].

Daily, the adrenal gland secretes between 24 and 30 mg of cortisol, while during stress it can produce up to 300 mg [1]. Doses of exogenous corticosteroids of 30 mg or more for 14 days or longer cause inhibition of the hypothalamic-pituitary-adrenal axis, and consequently it takes longer for the body to respond to a stressful

Anti-inflammatory effect	Immunosuppressive effect
• Inhibition of phospholipase A activation	• Decrease in the number of lymphocytes
• Prevention of leukocyte and macrophage migration	• Decrease in the amount of immunoglobulin
• Inhibition of fibroblast proliferation	• Reduction of the body's response to the antigen-antibody reaction
	• Inhibition of macrophage activity

Table 1.
Anti-inflammatory and immunosuppressive effects of corticosteroids.

situation [1]. The most important role of cortisol is gluconeogenesis, a process that increases the glucose level and the ability of the body to react in stressful situations [1]. Corticosteroids also have anti-inflammatory and immunosuppressive effects (**Table 1**) [1].

Considering the mentioned effects, corticosteroids are one of the most useful drugs in pharmacotherapy in general.

In regular clinical practice, corticosteroids have been used against a number of inflammatory and immune-mediated diseases and conditions for more than 50 years. In 1950, the Nobel Prize was awarded to Kendall, Reichstein, and Hench for the detection of these very important biologically active molecules [2].

Many diseases with oral mucosal manifestations such as oral lichen planus (OLP), pemphigus vulgaris (PV), mucous membrane pemphigoid (MMP), and systemic lupus erythematosus (SLE), as well as chemical injuries, traumatic lesions, and recurrent aphthous ulcers (RAU), are mostly successfully treated with corticosteroids.

The most commonly used systemic steroids are dexamethasone, prednisolone, methylprednisolone, and hydrocortisone [3]. Topical steroids commonly used in oral medicine practice are triamcinolone acetonide, clobetasol propionate, fluocinonide, and betamethasone [4]. While the use of topical corticosteroids is generally safe, systemic therapy needs some specific considerations, particularly in patients undergoing invasive dental procedures.

2. Topical corticosteroids

Corticosteroids are the gold standard for the management of many diseases in all medical areas. The use of corticosteroids has significantly improved treatment protocols for various oral diseases and conditions and has become indispensable in everyday clinical practice.

Topical corticosteroids are the first-line of therapy for patients with chronic inflammatory diseases of the oral mucosa. Most of such oral diseases can be controlled with topical high-potency corticosteroid preparations, which have been proven to be highly effective and have fewer side effects than systemic steroids [5]. Effect of topical steroid preparations involve vasoconstriction, reduced mast cell degranulation, and capillary permeability, causing a decrease in the amount of released histamine [3]. The formulations of topical steroids most commonly used in oral medicine practice are orabase ointments and aqueous solutions. The recommendation for using an orabase ointment is to apply a small amount of it to the lesion area and not eat or drink for 30 minutes. It is advisable to use orabase ointments when treating small, solitary lesions and in cases where there are a few lesions that are easily accessible. Furthermore, lesions localized on the gingiva or palate can be treated with orabase ointments using customized trays, which allow excellent control of the time period in which the drug must come into contact with the lesion [4]. Benefits of using aqueous solutions are perfect control of time contact between lesion and drug and drug contact with all lesions regardless of their size and depth. Aqueous solutions are the formulations of choice for the treatment of large and extensive lesions. It is easier for the patients to use corticosteroids in the form of aqueous solutions than orabase ointments. The main disadvantage of using aqueous solutions is that even healthy oral mucosa comes into contact with the drug, increasing the risk of systemic absorption and ingestion [4].

The potency of topical steroids depends on the amount of vasoconstriction they produce. According to potency, topical corticosteroids are divided into mild, moderate, potent, and very potent preparations [4]:

Mild

- 1% hydrocortisone acetate
- 0.05% alclomethasone dipropionate
- 0.25% methylprednisolone acetate

Moderate

- 0.05% clobetasone butyrate
- 0.1% hydrocortisone butyrate
- 0.5% fluocortolone pivalate

Potent

- 0.025% beclomethasone dipropionate
- 0.05% betamethasone dipropionate
- 0.025% betamethasone benzoate
- 0.1% betamethasone valerate
- 0.1% diflucortolone valerate
- 0.025% flucinolone acetonide
- 0.05% fluticasone propionate
- 0.05% flucinonide

Very potent

- 0.05% clobetasol propionate
- 0.3% diflucortolone valerate
- 0.01% halcinonide.

Topical steroid preparations most often used in the treatment of oral mucosal diseases are clobetasol propionate, flucinonide, and triamcinolone acetonide [4]. These preparations belong to the group of potent and very potent topical steroid preparations.

2.1 Perilesional/intralesional corticosteroid injection

Perilesional/intralesional corticosteroid injection (P/ICI) is a form of topical application of the drug which ensures a high concentration of drug at the site of lesion. Although it is mentioned in the literature mainly as an intralesional injection, it is important to distinguish between the use of perilesional and intralesional corticosteroid injections. Perilesional injection is used in the treatment of major aphthous ulcers, decubitus, and other major erosions and is applied around the lesion. Furthermore, the intralesional injection is applied directly into the affected tissue, as in the case of orofacial granulomatosis.

This type of application has minimal systemic absorption and therefore no systemic side effects [6]. The most commonly prescribed drugs for P/ICI are triamcinolone and methylprednisolone [6]. Prior to P/ICI administration, a medical history must be taken from patients to rule out allergies and other medical issues that could affect the procedure. An insulin syringe is most suitable for the administration of P/ICI. Typically, 0.1–0.2 mL of the drug is injected at four sites around the lesion or directly into the lesion, with a total dose of 2 mL of the drug for each treatment session (**Figure 1a**, **b**). Before the application of P/ICI, local anesthesia can be used, which is mostly not the case due to similar pain when applying both drugs [7].

2.2 Side effects of topical corticosteroid therapy

Topical corticosteroids are applied directly to the oral mucosa with minimal systemic absorption, so side effects occur much less often than with systemic therapy, especially if the treatment is not prolonged. However, as a result of long-term use of topical preparations, local side effects such as oral candidiasis and atrophy of the oral mucosa have been described [8]. Oral candidiasis can be prevented by using antifungals or chlorhexidine mouthwash solutions [9].

In addition to the above, as a result of systemic absorption, cases of hirsutism and a moon face between the 4th and 6th week of therapy with topical steroid preparations have also been recorded in the literature [10]. Cases of dry mouth, bad taste and smell, swollen lips, and nausea are described less often [11].

Cases of hairy leukoplakia, hypersensitivity reactions of the oral mucosa, hemorrhagic effusions on the skin and mucous membranes, and iatrogenic Cushing's syndrome have also been described in the literature [12–15].

Figure 1.
(a and b) The use of perilesional injection with methylprednisolone and an insulin syringe for treatment of traumatic ulcer.

The mentioned side effects, such as Cushing's appearance and hirsutism, are related to systemic absorption due to long-term use of topical steroid preparations. However, it remains unclear whether the listed side effects occur as a result of direct absorption of the topical steroid preparation from the oral mucosa or as a result of unintentional ingestion, or are the result of potential risk factors such as the age of the patient, treatment method, use of additional drugs, time of application, localization, and size of the lesion, as well as the presence of more extensive ulcerations, which has not been investigated so far [15].

The most common and immediate side effects of P/ICI application are pain and bleeding. Less frequently, allergic reaction, infection, mucosal atrophy, and hypo- or hyperpigmentation can occur [7, 16].

3. Systemic corticosteroids

The use of systemic corticosteroids is reserved for severe, erosive, and stubborn cases of OLP, RAU, and MMP that do not respond to topical steroid therapy, as well as for PV lesions, and is prescribed according to a strict regimen with a gradual dose reduction [17].

The dose of systemic corticosteroids depends on the type and severity of the disease and the patient's individual response. Initially, relatively high doses are applied, which are significantly higher in severe acute forms than in chronic diseases. Prednisone and methylprednisolone are prescribed in doses of 1.5–2 mg/kg/day and after clinical improvement, the initial dose is gradually reduced. Depending on the clinical symptoms and the individual patient's reaction, the dose can be reduced to the lowest possible maintenance limit (5–15 mg of prednisone per day) in different time intervals [18]. Chronic diseases often require long-term treatment with low doses. General dosing guidelines in accordance with relevant literature data are presented in **Table 2** [18]. The most commonly used glucocorticoid for long-term control of oral diseases is prednisolone. Rarely, dexamethasone can be given, which is 5–6 times stronger than prednisolone; therefore, it

Dose	Dose mg/day	Dose mg/kg/body weight/day
High	80–100 (250)	1,0–3,0
Medium	40–80	0,5–1,0
Low	10–40	0,25–0,5
Very low	1,5–7,5 (10)	–/–

Table 2.
Dosing guidelines for systemic corticosteroids (prednisolone).

is given in a much lower dose. Dexamethasone is not appropriate for long-term systemic administration because its long action does not allow the hypothalamic-pituitary-adrenal (HPA) axis to recover [19].

Dose reduction begins when the desired clinical effect has been achieved. Furthermore, if the daily dose is divided into several individual doses, the evening dose is reduced first, and then, if applicable, the midday dose. Initially, the dose is reduced in slightly larger steps, and from a value of about 30 mg per day downward, in smaller steps. The clinical picture of the disease determines whether the treatment should be stopped completely or whether a maintenance dose is required [18]. With careful disease monitoring, the following scheme can be applied as an orientation for dose reduction (**Table 3**) [18].

3.1 Side effects of systemic corticosteroid therapy

Systemic corticosteroid therapy has significantly more serious and frequent side effects than topical preparations. Long-term use of systemic corticosteroids causes suppression of the adrenal gland, which leads to a life-threatening condition called adrenal crisis, characterized by hypotension, nausea, cardiovascular collapse, stroke, coma and, in the most serious cases, death [1]. In addition to the adrenal crisis, long-term use of systemic steroid therapy can cause a number of side effects, such as:

- Cushingoid appearance—moon face, hirsutism, bison hump, central obesity
- Skin atrophy, capillary fragility, and tendency to bruises
- Loss of muscle mass
- Gastritis, ulcers, bleeding from the gastrointestinal tract
- Osteoporosis

>30 mg	reduction by	10 mg	every 2–5 days
30–15 mg	reduction by	5 mg	every week
15–10 mg	reduction by	2,5 mg	every 1–2 weeks
10–6 mg	reduction by	1 mg	every 2–4 weeks
˂ 6 mg	reduction by	0,5 mg	every 4–8 weeks

Table 3.
Dose reduction scheme for systemic corticosteroids.

- Hypertension
- Hyperglycemia
- Headaches
- Cataracts
- Immunosuppression
- Mood changes [1].

The irreversible side effect of long-term use of systemic corticosteroid therapy is osteoporosis, a condition that increases the risk of developing bone fractures. Densitometry, serum calcium levels, phosphorus, and 25-hydroxyvitamin D should be performed in these patients to avoid possible complications during invasive dental procedures [19]. The European League Against Rheumatism (EULAR) group has given recommendations for monitoring and prophylaxis for long-term glucocorticoid treatment [20], but data from the literature suggest that monitoring of these patients should be improved in daily practice [21]. In addition to systemic corticosteroid therapy, a patient should receive antacids and a proton pump inhibitor as prophylaxis against peptic ulceration, and all other parameters should be adequately followed-up, such as blood pressure, glucose, and eye survey [20].

Adrenal insufficiency, Cushing's syndrome, diabetes, hypertension, and osteoporosis are potential problems that may require modification of the dental procedure. Therefore, dental care modifications in patients on long-term systemic corticosteroid therapy will be mentioned in the following text.

4. Recommendations for the dental management of patients receiving systemic corticosteroid therapy

In everyday clinical practice, systemic corticosteroids are used in the treatment of a number of inflammatory and immune-mediated diseases and conditions, including autoimmune diseases and prevention of transplant rejection. During stress, in healthy individuals the level of cortisol normally doubles, while in the case of adrenal insufficiency, a sufficient amount cannot be produced. Therefore, in these patients, in stressful situations (during acute infection, surgery, trauma, sudden interruption of long-term therapy, or in a patient exposed to a strong physical or psychological stress), a life-threatening condition, an adrenal crisis, can develop [1].

Patients with Addison's disease, other forms of adrenal gland insufficiency, and patients on systemic steroid therapy for more than 3 weeks are at risk of developing an adrenal crisis. (7.5 mg/day prednisone) [1]. There is a lack of more recent agreed positions regarding the dental management of patients on systemic corticosteroid therapy. The primary reference that dentists usually follow is Gibson et al. [22] or the integrated clinical environment (ICE) Health Systems platform guidelines [23].

Before stressful procedures, major surgeries, or procedures under general anesthesia:

- If patient has been taking more than 7.5 mg of prednisone per day for more than 3 weeks and the procedures are performed within 3 weeks of discontinuation of corticosteroids, the patient should be given an earlier maintenance dose in the morning before the procedure.

- If patient is currently on more than 7.5 mg of prednisone, a double daily dose is given on the day of the procedure and an additional single dose on the first postoperative day if pain is present.

- When the patient is taking the medicine every other day, the procedure is performed on the day of taking the medicine, in a double dose [24, 25].

Routine dental procedures, including minor surgical procedures (simple extractions, biopsy, minor periodontal surgery …) performed under local anesthesia:

- Do not require additional corticosteroid administration if the patient is on a daily maintenance dose higher than 7.5 mg of systemic prednisone or uses corticosteroids every other day.

- In patients who take corticosteroids every other day, the procedure is performed on the day of drug intake.

- If patient has been taking more than 7.5 mg of prednisone per day for more than 3 weeks, and minimally stressful procedures are performed within 2 weeks of corticosteroids discontinuation, the patient should be given previous maintenance dose in the morning before the procedure [24, 25].

Recently published Addison's Self-Help Group guidelines suggest that patients with adrenal insufficiency or who are at risk of adrenal insufficiency should receive 100 mg of hydrocortisone intramuscularly before all dental extractions [26].

These guidelines completely invalidate the dentist's assessment of the invasiveness of the procedure, and it is known that most tooth extractions and similar interventions are considered minor procedures that do not result in significant stress. When there are concerns, it is rational to consult with endocrinologist.

Dental procedures should be done in the morning, within 2 hours of taking the regular therapeutic dose. It is also important to reduce stress as much as possible with sedation, prevent intraoperative pain (long-acting local anesthetic) and ensure adequate postoperative analgesia [24, 25].

5. Conclusion

Topical and systemic corticosteroids are one of the most common drugs used in oral medicine practice for the treatment of a large number of oral mucosal diseases. Due to their anti-inflammatory effect, they are used to reduce edema and pain in many acute and chronic conditions. In addition, they also have an immunosuppressive effect, so long-term use, especially of systemic corticosteroids can cause a series of side effects, some of which are even life-threatening. Despite unwanted side effects and caution when prescribing, the use of corticosteroids has no alternative in clinical practice for many conditions.

Conflict of interest

The authors declare no conflict of interest.

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Section 4

Preventive and Restorative Approaches in Dentistry

Chapter 9

Dental Caries Prevention

Vesna Ambarkova

Abstract

Various forms of fluoride have been used in dentistry for the past 70 years to prevent tooth decay. The results have been very successful, which is why the frequency and prevalence of dental caries in the 1990s significantly decreased compared to that of the 1950s. Fluoride caries prevention originates from mechanisms that act before and after tooth eruption. In the period before tooth eruption, the introduced fluorides are incorporated into the hydroxyapatite crystal, reducing the solubility of the enamel. The calcification of primary teeth begins in the fifth month of pregnancy, and the creation of the enamel of the permanent teeth occurs at birth and ends from the 12th to the 16th year of life. Fluorides are incorporated into the tooth tissue during the period of mineralization. In the period after the teeth erupt and after the ingestion of fluorides from various sources (fluoride tablets, fluoridated drinking water, table salt, milk and/or fluoride toothpastes), a new phase of mineralization occurs (i.e., rebuilding of the enamel matrix). It has been proven that the cariogenic bacterium Streptococcus mutans becomes less acidogenic due to its adaptation to an environment in which there is regular exposure to low concentrations of fluorides in drinking water or higher concentrations of fluorides from toothpastes and mouthwashes. Therefore, the purpose of this chapter is to summarize the literature on dental caries prevention.

Keywords: fissure sealants, preventive dentistry, dental caries, fluoride toothpaste, fluoride varnish

1. Introduction

Preventing dental caries (tooth decay) is of paramount importance due to its significant impact on both oral health and overall well-being. Dental caries is one of the most prevalent chronic diseases globally, affecting individuals of all ages, particularly children and vulnerable populations. Here are some key aspects that underscore the global importance of preventing dental caries. Untreated caries can cause various consequences: diseases of the oral cavity, digestive system, psychological trauma, and sometimes disability. Therefore, the impact of caries on the general health of the individual and the entire population should be especially emphasized. In addition to the health impact, the social impact is also very important. In fact, the treatment of caries in every society has its own price, which increases with the extent of neglect and non-treatment of the disease. Therefore, society should organize and develop the dental service so that prevention takes a leading place and becomes a permanent, efficient, and systematic activity [1].

The cause of dental caries is still not completely clear, although many factors are directly or indirectly linked to its occurrence. In the past, we divided all these factors into two groups: Predisposing factors—nutrition, lack of vitamins (A, C, and D), mineral salts (Ca and P), hereditary factors, hormonal disorders, unfavorable climatic and microclimatic conditions, previous general diseases, retention sites on the teeth, poor tooth structure, improper oral and dental hygiene, lack of fluoride; Causative factors—the role of acids, acidogenic and proteolytic bacteria and proteolysis, the role of enzymes, and so on. The progress of research and knowledge of the etiopathogenesis of the carious process has made it possible to understand this dynamic process that takes place between the biofilm and the tooth surface, where a continuous exchange of ions takes place, as well as the processes of re- and demineralization, especially after food intake. Most often, the demineralization that occurs can be quickly compensated by the reserve amount of calcium, phosphorus, and magnesium in the saliva, but when the delicate balance on the side of demineralization is disturbed, then the loss of minerals leads to the development of a carious lesion. Such an imbalance occurs when the causative agents overcome the defensive factors for a certain period of time [2].

According to the modern theory of caries, it is a multicausal disease, the result of the interaction of multiple factors in the oral environment, such as the existence of a susceptible host, cariogenic microorganisms, and a suitable substrate, present over a certain period of time [3].

2. Causes and risk factors

2.1 Bacteria

Dental caries is a process that involves the demineralization of tooth enamel and the underlying dentin due to acid produced by bacteria in the mouth. Role of Streptococcus mutans and Lactobacillus in the development of caries is very important. Streptococcus mutans and Lactobacillus are two key bacterial species that play significant roles in the development of dental caries (tooth decay). The mouth contains various bacteria, some of which are beneficial, but others are harmful. When sugar is consumed, harmful bacteria (such as Streptococcus mutans) feed on these sugars and metabolize them to produce acids as a byproduct. The acids produced by bacteria can lower the pH in the mouth, creating an acidic environment that is conducive to demineralization of tooth enamel. If the pH drops below a certain level (around 5.5 for enamel), demineralization begins [4].

2.2 Diet

Sugars contribute to the formation of dental plaque—a sticky biofilm that accumulates on teeth. Plaque harbors bacteria that continue to produce acids, further perpetuating tooth decay. The frequency of sugar consumption also matters. Frequent snacking on sugary foods can prolong the exposure of teeth to acids, giving the bacteria more opportunities to cause harm. Acidic foods (such as citrus fruits, soft drinks, and vinegar) contain acids that can directly erode tooth enamel. This erosion weakens the enamel and makes it more susceptible to decay. Regular consumption of acidic foods can lower the overall pH in the mouth, similar to the effect of sugar. Enamel begins to demineralize at a pH of around 5.5, so prolonged exposure to acidic substances can further accelerate this process. When acidic foods are consumed in combination with sugars, the likelihood of tooth decay increases. The acids from the foods can weaken enamel, and the sugars can feed decay-causing bacteria, leading to a compounded effect [5].

2.3 Genetics

Genetics plays a significant role in the susceptibility to dental caries (tooth decay), influencing various factors that contribute to the health of teeth and the oral environment. Several genetic factors can affect the development of dental caries, including: tooth structure and composition and saliva composition. Genetic variations can influence the thickness and mineral composition of tooth enamel. Thicker enamel that is more mineralized is generally more resistant to acid erosion and decay. The composition and structure of dentin (the layer beneath enamel) can also be genetically determined. Variations in dentin can affect its strength and how it responds to decay. Genetics can influence salivary flow rates, which are crucial for maintaining oral health. Saliva helps neutralize acids, remineralize teeth, wash away food particles, and control bacterial growth. The antibacterial properties of saliva, including immunoglobulins and other proteins, can vary genetically, affecting an individual's ability to resist tooth decay. Genetic factors can influence the composition of an individual's oral microbiome, including the types and proportions of bacteria present. Certain bacterial profiles are associated with a higher risk of caries, while others may be more protective [6].

2.4 Age

Children and older adults are at higher risk of dental caries. Older adults are at increased risk of root caries, because of both increased gingival recession that exposes root surfaces and increased use of medications that produce xerostomia; approximately 50% of persons aged older than 75 years of age have root caries affecting at least one tooth [7]. Superficial carious lesions are more frequently detected in the younger population [8].

2.5 Poor oral hygiene

Inadequate brushing and flossing allow plaque buildup [9].

2.6 Socioeconomic factors

Limited access to dental care, education, and preventive measures can have significant negative impacts on oral health and overall well-being. In many areas, particularly rural or underserved urban regions, there may be a lack of available dental services. This can lead to inadequate preventive care and delayed treatment for existing issues, increasing the likelihood of progression from early caries to more serious dental problems. Dental care can be expensive, and those without dental insurance or financial resources may delay or forgo necessary treatments. This lack of access can exacerbate dental issues, leading to higher rates of caries. For many individuals, transport barriers or the inability to travel to a dental office due to distance, lack of transportation, or mobility issues can be significant barriers to receiving care. Limited education about oral health, proper brushing and flossing techniques, and the importance of regular dental visits can lead to poor oral hygiene practices among individuals and families, increasing the risk of dental caries. Lack of education about nutrition and its impact on dental health may result in diets high in sugars and acids, further contributing to the risk of caries. In some communities, cultural factors like beliefs and practices may impact attitudes toward dental care, preventive measures, and the value placed on oral health [10].

3. Preventive measures

3.1 Oral hygiene practices

It's important to brush at least twice a day with fluoride toothpaste. Remove interproximal plaque to prevent caries between teeth by flossing.

3.2 Fluoride use

The precise molecular and cellular mechanisms of fluoride action on caries are still unclear. The influence of factors such as genetics, environment, age, diet, gender, and the influence of drugs on fluoride metabolism (bioavailability, uptake, and excretion) still needs to be further elucidated.

In areas where fluoridation of drinking water is not feasible or permitted, it can be replaced by fluoridation of some food products, primarily table salt and milk, as well as the use of fluoride tablets. The only advantage of these alternative methods over fluoridation of drinking water is that they leave room for the individual to choose. The first fluoridation of table salt was carried out in Switzerland in 1955, and somewhat later in Hungary and Colombia. The amount of fluoride added to table salt varies and ranges from 90 to 250 mgF^-/L. The results of some published studies indicate that caries decreased in 18 to 65% of the subjects. This percentage is directly related to the amount of fluoride added to the table salt. In fact, in the age group that consumed low amounts of fluoride from table salt (90 mgF^-/L), caries decreased in 18% of the subjects, and in the group that consumed table salt of 200–250 mgF^-/L, caries decreased in 36–65% of the subjects. However, caution should be exercised when adding fluoride to table salt due to the possibility of cardiovascular diseases in people with high blood pressure [11]. Fluoridated table salt comes in 1 kg packages, is clearly marked, and may only be sold where the amount of fluoride in the water is less than 0.5 mg/L. The advantage is that it is cheap, but the disadvantage is that adults use more salt, so children need to take fluoride tablets in addition.

4. Artificial fluoridation of drinking water today

Naturally fluoridated water is consumed by 4% of the world's population. In the European Union (EU), only the United Kingdom, Spain, and Ireland apply the measure of artificially regulating the concentration of fluoride in water. The Republic of Ireland and Singapore are the only countries that implement mandatory water fluoridation.

Implementation of the measure of artificial fluoridation of drinking water should be done under certain conditions (WHO [12]):

- The prevalence of dental caries in the community is moderate or high or there is strong evidence that it is increasing, so water fluoridation can be a mass preventive measure.

- The candidate country or region of the country has an average level of economic and technological development.

- The existence of a central drinking water supply must be ensured; if available, the water must be of sufficient quality, and the water supply network must be modern and extend to a large number of households (>10,000 inhabitants).

- The inhabitants must be proven to consume water from the water supply network and not from a private source or bottled water.

- The necessary equipment must be technologically sufficient for the safe addition of the fluoride compound to the water.

- The fluoride salt should be of acceptable quality, the stock should be kept safe, sufficient for a reasonable period of time, and its raw material supply should be guaranteed.

- The responsible personnel of the artificial fluoridation unit should be adequately trained, both in the maintenance of mechanical equipment and in the daily control of the concentration of fluoride ions in the water before and after channeling it to the network, keeping detailed records of measurements and events.

- The funds must be sufficient and provided, both for the initial installation and operation of the unit, as well as for the maintenance of all equipment.

Today, artificial water fluoridation has ceased to be the cornerstone of public prevention programs for all countries.

Milk fluoridation is carried out with the assumption that those who need it the most (pregnant women, nursing mothers, infants, and children) will receive the fluoride. Milk is fluoridated in the United Kingdom, Bulgaria, Chile, China, and Russia. Except in Chile, where the milk is in powdered form, in other countries, pasteurized milk is fluoridated. Typically, 5 mg/L is added to milk [13]. Although studies of milk fluoridation have been known since 1956, this method cannot be accepted as a general preventive method, since milk is consumed mainly by children, in varying quantities. However, this method can only be accepted as a local method, for example, if fluoridated milk is given to school children at mealtimes [14]. Fluoridated milk and fluoridated salt can be used as preventive measures in the public health system, among target groups with a high prevalence of caries and among those who do not have the habit of brushing their teeth, in regions where there is no water fluoridation.

4.1 Fluoridation with fluoride tablets

This type of fluoridation is carried out individually, on the recommendation of pediatric dentists depending on the caries risk. The negative side of fluoridation through fluoride tablets is that it leaves freedom to each individual to adhere to the recommendations of the dentist or not at will. Fluoride tablets are known and have been used for decades. They were originally used to meet the need for fluoride in regions where it was not available in drinking water. The EAPD (European Academy of Pediatric Dentistry) supports the view that the daily use of fluoride is an essential part of any comprehensive preventive program for caries control in children. Regardless of whether the program is individual or more broadly socially organized, the proposed use of fluoride must be balanced between the assessment of the caries risk and the possible risk of toxic effects of fluorides. Such a preventive program should be reevaluated at certain intervals and adapted to the needs and risks for patients. Some patients have an increased risk of caries and are called high-risk patients. In particular, newly erupted teeth are more susceptible to caries, and certain ages can also be at risk and are called high-risk ages. Preschool children often develop caries before the age of three, especially if they are from lower social classes, and preventive activities should be considered for them. There are several studies on the effectiveness of fluoride tablets and drops, but none of them are sufficiently robust. Some of the studies used tablets, some drops in combination with vitamins, and some results were achieved, but a standard strategy for their use cannot be achieved [15]. Fluoride tablets and drops can be used in individual cases in children at high risk of caries.

- 0 to 24 months——not recommended.
- 2 to 6 years——0.25 mg/day fluoride.
- 7 to 18 years——0.50 mg/day fluoride.

If the fluoride level in drinking water is 0.3–0.6 mg/l, no fluoride supplements should be used except fluoride toothpaste in children aged 2–3 years, and in older children, daily supplements should be reduced to 0.25 mg/day (Guidelines on the use of fluoride in children: an EAPD policy document).

4.2 Local fluoridation

4.2.1 Fluoride toothpastes

The use of fluoride toothpastes is almost universal, but other sources of fluoride can also provide additional benefits when an individual's caries risk is high. Given that the systemic effect of fluoride plays a minor role in caries inhibition, it is debatable whether fluoride should be used only topically and not systemically. However, the efficacy and safety of fluoridated water indicate that systemic fluoride intake may be acceptable if this method of delivery is the most appropriate. The cariostatic effects of fluorides when applied topically occur mainly on the enamel surface. Today, however, it is believed that the topical action of fluoride is the one that provides the greatest effect. The main preventive effect of topically applied fluoride is primarily achieved by creating a fluoride reservoir in saliva and plaque and by ensuring the maturation of enamel after tooth eruption and the formation of calcium fluoride (CaF_2) on the enamel surface, which is resistant to acids, even up to 10 times more resistant than other compounds contained in hard dental tissues. The caries preventive effect of fluorides may also include the inhibitory effect on the oral flora involved in the occurrence of caries. The ability of fluorides to inhibit glycolysis through interference with the enzyme enolase has long been known. It has been established that fluoride concentrations of about 50 ppm interfere with bacterial metabolism. Fluorides can accumulate in dental plaque at concentrations above 100 ppm. Also, fluorides normally present in plaque in ionic form can interfere with acidic products of bacterial metabolism. They can react with dissolved enamel, promoting its remineralization in the form of fluorohydroxyapatite. The end result of this process is the physiological restoration of the initial lesion through enamel remineralization and the formation of a more resistant enamel surface [16–20].

Topical fluoridation, regardless of the form of preparation used (organic or inorganic), acts to [21, 22]:

- Reduce the solubility of hard dental tissues in the acidic environment of plaque;
- Accelerate remineralization;
- Perform enzymatic inhibition during glycolysis, thereby reducing acids;
- Prevent the synthesis of intra and extracellular polysaccharides;
- Have a bacteriostatic and conditionally bactericidal effect; and
- Reduce the viscosity of saliva.

5. Fluoride gels, rinses, and varnishes

Topical fluoride is used in children who are assessed as potentially at high risk for developing caries, including children with special needs **Table 1**.

Fluoride supplements	Instructions for use
Fluoride varnish (professional use, typical concentration 22,600 ppmF)	• It should be used to prevent caries in the primary and permanent dentition. • varnish is the only high fluoride topical agent that can be used in preschool. • application 2–4 times/year • Visible dental plaque should be removed before application. • clinicians should use a thin film using a minimal amount on caries predilection sites, initial caries lesions and defects, according to manufacturer's instructions. • the child should avoid taking food or liquids for the next 20–30 minutes
Jelly (professional use, typically concentration 5000–12,300 ppmF)	• Do not use in children under 6 years of age (the risk of swallowing is greater than the benefit of its use) • application 2–4 times/year • before application, visible deposits of dental plaque should be removed and selected appropriate size trays. Patient should sit in upright position and not swallow; use suction devices during treatment and after tray removal to minimize swallowing of the jelly. • the child should avoid taking food or liquids for the next 20–30 minutes
Mouthwash solutions for home use or use in schools. Typical concentrations for daily use: 0.05% NaF [225 ppmF], 500 ppmF for older people For weekly use: 0.2%. NaF [900 ppmF]	• Do not use in children under 6 years of age (because the risk of swallowing is greater than the benefit of use) • use under adult supervision is more effective • Rinse the mouth with 5 ml (small children) or 10 ml (adolescents) for 1 minute. • the child should avoid taking food or liquids for the next 20–30 minutes

Table 1.
Recommendations for additional use and application of fluoride supplements.

5.1 Gels for professional use (5000–12,500 ppm F)

Fluoride gels have been shown to be effective in preventing caries in permanent dentition, while in deciduous dentition, there is no greater result. Their use is not recommended for children under 6 years of age due to the risk of swallowing and is recommended for adults as a caries prevention. They should be used 2–4 times a year. Before use, the teeth are cleaned of soft deposits, then the chair is placed in an upright position, a suction device is turned on, and the gel is filled into individually prepared templates. After the session, the teeth are wiped with gauze, and eating and drinking are not recommended for the next 30 minutes [15].

5.2 Fluoride mouthwashes

There are mouthwashes for daily use with a concentration of 0.05% NaF (225 ppm F) and for weekly use with a concentration of 0.2% NaF (900 ppm F). There are no data on their effectiveness in baby teeth, but they have been proven effective in permanent dentition. They are not recommended for children under 6 years of age due to the risk of swallowing and are recommended for use in adults. Take a sip of about 10 ml and swish it in your mouth for about a minute, then spit it out. Do not eat or drink for 30 minutes afterward.

5.3 Fluoride varnishes

The varnishes are for professional use and contain 1000–56,300 ppmF. They are effective in preventing caries in both primary and permanent dentition, and both their use is recommended for 2–4 times a year. Before use, clean the soft deposits and apply the same precautions as for gels. Apply a thin film of varnish, paying particular attention to the amount of varnish in areas at risk of swallowing. After use, do not eat or drink for 30 minutes.

5.4 Toothpastes with fluoride

The use of fluoridated toothpastes is probably responsible for the dramatic reduction in caries that has been recorded over the past 30 years. Brushing teeth with fluoridated toothpaste is an almost ideal public health method because its use is practical, inexpensive, culturally acceptable, and widespread. A potential hazard of fluoride toothpastes is the possibility of swallowing during their use, which is especially dangerous in children under 3 years of age due to the development of fluorosis. Therefore, parents should be advised to use only a pea-sized amount of toothpaste for young children and to supervise them when brushing their teeth until the age of 7. The use of toothpaste with a lower fluoride concentration may also be recommended, but the effectiveness of toothpastes with a fluoride content of less than 500 ppm F has not been sufficiently studied. Brushing teeth with fluoride toothpaste in children should be extended by one minute with each subsequent brushing, and children should be taught to spit out the toothpaste and not rinse it with water. There is no official recommended time for brushing teeth, but it is common to do so at night before going to bed. Eating after brushing should be avoided. Brushing can be done manually or with an electric toothbrush with a small, soft-bristled head [15]. Where brushing is combined with other fluoride supplements, the cumulative effect of fluoride in children under 6 years of age should be considered. A careful balance must

Age	Fluoride concentration	Frequency	Amount (gr))	Size
From birth, eruption of the first tooth to <2 years	1000 ppm	2 times/day, morning-evening	0.125	Spreadable layer or grain of rice
2 to <6 years	1000 ppm*	2 times/day, morning-evening	0.25	grain pea
> 6 years	1450 ppm	2 times/day, morning-evening	0.5–1.0	1–2 cm

**In children aged 2 to <6 years with an increased risk of developing caries, the use of higher concentrations is considered*

Table 2.
Use of fluoride toothpaste.

be struck between maximizing the caries-protective effect of fluoride and minimizing the risk of fluorosis. This should be done in conjunction with the physician's experience and the patient's priorities. The socioeconomic conditions of the patient should also be taken into account when making recommendations for fluoride use [15]. Recommendations for the use of fluoride toothpastes in relation to the age of children are shown in **Table 2**.

Recommendations for the use of fluoride toothpaste in children:

- 0 to <2y——1000 ppm——twice a day spreadable layer or grain of rice.
- 2y to <6y——1000* ppm——twice a day as a pea.
- 6y and over——1450 ppm——twice a day 1–2 cm.

5.5 Chewing gum

Chewing gum causes an increase in flow velocity, and its consequences increase the regulatory capacity of saliva, as does any food that requires chewing effort. When chewing fluoride gum, fluoride ions are released into saliva at a rapid rate and contribute to an increase in its calcification power. There are commercially available fluoridated chewing gums with a concentration per mouth of 0.25 mg F. It is recommended to chew immediately after eating and for more than 20 minutes [23].

6. Dietary recommendations

Preventing dental caries, or tooth decay, involves a combination of good oral hygiene practices and dietary habits that minimize the risk of plaque formation and acid attacks on teeth. Dietary recommendations designed to reduce the risk of dental caries are limitation of the sugary foods and beverages; minimized intake of foods with hidden sugars, such as processed snacks, sauces, and beverages; and consuming of sugary treats with meals rather than as snacks. Incorporation of protective foods (dairy products, fibrous foods, and green and black teas) in daily meals is very important, because they help remineralize enamel and buffer oral acids. Fruits and vegetables like carrots, celery, and apples stimulate saliva flow, aiding in cleaning the teeth. Green and black teas contain polyphenols that can inhibit bacterial growth and reduce plaque formation [24].

7. Sealants

Fluorides are highly effective in reducing the number of carious lesions that occur on the smooth surfaces of enamel and cement. However, fluorides are not equally effective in protecting occlusal pits and fissures, where 95% of all carious lesions occur. Considering the fact that occlusal surfaces account for 12% of the total number of dental surfaces, this would mean that pits and fissures are on average eight times more vulnerable than smooth surfaces [25]. It is recommended that the treatment be carried out selectively, based on individual caries risk and according to the anatomy of the fissures. However, it is difficult to predict the occlusal caries of the permanent first molars with the help of the previous experience with the caries in the deciduous dentition, especially if one takes into account the fact that the assessment of "deep occlusal anatomy" varies from one practitioner to another. In the literature, various study tests for the effectiveness of the retention are presented [26–29]. This preventive method combined with frequent exposure to fluorides, education, and motivation for proper oral hygiene can reach 100% protection from occlusal caries. The assessment of the effectiveness of fissure sealing is a complex function of the retentiveness of the materials used for fissure sealing and the degree of caries reduction in teeth where this preventive measure is applied.

The dental industry offers several types of sealants for sealing fissures and pits. They differ according to their chemical composition (constituent components), method of polymerization, and other characteristics, and of course, from generation to generation, they improve their properties. Sealing as a method of protection against occlusal caries in fissures and pits has been applied since the beginning of the last century, and its methodological procedure is classic and simple [25]. Dental sealants act as a primary prevention barrier against plaque and acids, by forming a hard shield that prevents food and bacteria from getting into these vulnerable areas on the chewing surface of the tooth and causing dental caries. Dental sealants are also an effective secondary preventive approach when placed on early non-cavitated carious lesions, by inhibiting caries progression [30]. According to the literature, fissure sealant materials fall into two main categories: resin-based sealants and glass ionomer sealants. Even if the "fluoride-releasing resin sealants" are better than "glass ionomer," with regards to retention of the material, the literature shows that their effectiveness in preventing fissure caries in permanent molars does not differ significantly over 24 months [31, 32].

8. Methods of stopping reversible carious lesion (remineralization of hard dental tissues-modern knowledge)

Restoration of lost enamel is one of the most challenging tasks in dentistry because enamel is formed only once in the human body and is avascular [33].

The requirements or conditions that remineralizing agents must meet are: They should deliver calcium and phosphate to the subsurface layer of enamel; should not deliver excess calcium; should not favor the formation of calculus; should work at an acidic pH of the oral environment to stop demineralization during a carious attack; should also work in patients with xerostomia, since saliva cannot effectively stop the carious process; and should be able to enhance the remineralizing properties of saliva, and new materials should be able to show some better properties compared to fluoride.

Remineralization agents are: fluorides, calcium phosphate based, calcium sucrose phosphate, xylitol, bioactive glass, and nano hydroxyapatite.

Fluoride remineralizing agents: Sodium fluoride (NaF), Stannous fluoride (SnF_2), Aminofluoride (Elmex® Gel, Elmex® Fluid), Sodium monofluorophosphate (MFP), Acidified Fluoride Preparation (APF).

Casein- Phosphopeptide/Amorphous Calcium Phosphate (CPP/ACP) is a complex that adheres to plaque, pellicle, and hydroxyapatite of enamel; stimulates remineralization; acts as a buffer in saliva; and reduces the effectiveness of plaque acids on the tooth surface; when used together with fluoride, the remineralizing effect increases, causing a greater reduction in the depth of the carious lesion through increased release of calcium, phosphate, and fluoride [34] .

Tricalcium Phosphate (TCP) Tricalcium Phosphate (TCP) is a mineral that, when added to toothpaste, provides calcium and phosphate ions to the surface of the teeth. It has a synergistic effect with fluoride, resulting in minimal pH reduction and reduced acidity conditions. The toothpaste (ClinPro Creme) that contains tricalcium phosphate among other ingredients is a promising hybrid material that shows a higher percentage of hardness recovery after demineralization [35].

Calcium sucrose phosphate in toothpaste strengthens the enamel more than nano hydroxyapatite and CPP-ACP and can be an alternative to the use of fluoride toothpaste in children [36].

8.1 Biomimetic remineralizing agents

Chitosan is a biocompatible polymer that accumulates on the inner wall of the bacterial cell and causes its aggregation and death; adheres to hard tooth surfaces, which makes it ideal for drug release; and has a negative effect on plaque formation, and as a carrier, it binds the amelogenin peptide. Together they achieve a double anticariogenic effect that leads to a complete stop of the progression of dental plaque, while the remineralization of the initial carious lesion is achieved over a long period of action. In the field of dentistry, it has gained immense popularity due to its natural existence and biocompatibility and reduced cytotoxicity. The chitosan structure is protonated by free amino groups and creates a positive charge around it. This property helps chitosan to bind to negatively charged structures such as tooth enamel. Additionally, chitosan can penetrate into the deeper layers of enamel, creating mineral content and thus helping in the remineralization of carious lesions. Hence, chitosan-based materials help in the remineralization of lost enamel and prevent the progression of carious lesions [37, 38].

Chitosan nanoparticles coupled with amelogenin in the form of a hydrogel help calcium and phosphate ions to reorganize and form an enamel-like structure [37]. This hydrogel has excellent antibacterial and remineralizing capacities while simultaneously improving the microhardness of the surface and subsurface parts of enamel.

Silver compounds are used in treating dental caries from century, and they are a simple and low-cost method in caries management techniques. Silver diamine fluoride (SDF) is composed of fluoride ion and diamine-silver ion. SDF reacts with calcium and phosphates in the saliva and forms fluorhydroxyapatite. Also, possible mechanism on the action of SDF on dental caries is Inhibition of Matrix Metalloproteinases, which breaks down extracellular components, and their presence in saliva and dentin plays an important role in dentin carious process. Silver diamine fluoride (SDF) is an effective agent for stabilizing active caries lesions based on the remineralizing effect of fluoride and the antibacterial properties of silver. Silver diamine fluoride (SDF) is used for the treatment of initial carious lesions of permanent molars affected by molar incisor hypomineralization (MIH) [39].

8.2 Probiotics

The mechanism by which probiotics can prevent dental caries is similar to that found in the gastrointestinal tract. The main inhibitory mechanisms include synthesis of active metabolites, inhibition of cariogenic microbial biofilm, competitive adhesion and colonization, co-localization with pathogens, and regulation of the immune system. The use of microbial preparations, such as probiotics, prebiotics, synbiotics, and postbiotics, in the prevention and treatment of dental caries can modulate the balance of the oral microbiota by introducing beneficial microorganisms or inhibiting pathogens. The pathogenesis of dental caries is closely linked to the balance of the oral microbiota. Therefore, future research should focus on gaining a deeper understanding of the characteristics and interrelationships between different beneficial and harmful microbial populations [40].

9. Conclusion

Prevention and interceptive approach have to be used as an imperative in everyday professional work. Our main goal should be to recognize the initial carious lesion, to act on it and to cure it using remineralizing agents, and to create greater resistance of the enamel. To maximize the remineralizing effect, it is necessary to create conditions for daily maintenance of oral hygiene, and a healthy and balanced diet is especially important. The emission of the properties of natural enamel includes the production of a protein matrix rich in amelogenin and its enrichment with calcium and phosphate. We will achieve optimal oral health if we effectively implement the following preventive strategies: Maintain regular oral hygiene, follow a balanced diet, regular dental checkups, fluoride treatments and sealants, use mouthwash, chew sugar-free gum, adopt healthy habits, and health education and motivation.

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Chapter 10

New Era of the Peri-Implant Diseases

Jae W. Chang

Abstract

The advent of "peri-implant diseases" marks a significant challenge in modern dentistry, arising as an inevitable consequence of the widespread integration of dental implants into routine dental care. The enigmatic issue is that dental implants became widely accessible to clinicians without the support of comprehensive training/education. From single implant crowns to full-arch prosthetics, the full spectrum of complexities in managing peri-implant tissues as a distinct disease entity remains a subject of evolving understanding. Due to the development of technology and media, there are suspected phenomena of 'minimizing gaps' between a non-specialized and a specialized clinician with years of full-time training. Although debates may exist regarding the clinical qualifications of different tiers of practitioners, the ultimate measure of success lies in patient outcomes. Patients bear the burden of experiencing both short- or long-term successes and failures, often intertwined with significant financial considerations. This may explain the growing demand to establish standardized credentials or distinctions, such as diplomate status, to recognize advanced expertise and ensure quality care. However, the question still remains whether such measures are sufficient to protect not only the public but also the clinicians. The current state of contemporary implant dentistry may not align with the optimistic portrayal often promoted by industry leaders. These industrial leaders focus on shaping public perception and leveraging marketing strategies to drive demand. What transpires subsequently? Is it genuinely a tale of sustained prosperity, or does it uncover more intricate results? This chapter seeks to examine the nascent "New Era of Peri-Implant Diseases.

Keywords: dental implants, oral implants, peri-implant diseases, peri-implant mucositis, peri-implantitis

1. Introduction

Earnest Armory Codman (1869–1940) was a Boston surgeon who explored creating hospital standards to test a surgeon's competency as well as to create an idea of a hospital register to support physicians in improving the quality of care. It was new to everyone, and he was shunned by his colleagues and lost his position as a faculty member of Harvard Medical School. He persisted and ended up creating the "End result system of hospital standardization" by creating the first bone tumor registry in the United States. His famous quote, in 1914, is still being used in the medical field to create a hospital standard.

> *"Every hospital should follow every patient it treats long enough to determine whether the treatment has been successful, and then to inquire 'if not, why not' with a view to preventing similar failures in the future."*

There are numerous registries in the medical field, such as RIKSHOFT, the Swedish Hip Fracture Register, the European Registry of Quality Outcomes for Cataract and Refractive Surgery (EUREQUO), the Dutch National Breast Implant Registry, and the Swedish Quality Registry for Caries and Periodontal Disease, to name a few. Similarly, for the first time in the dental implant field, the board of EAO (European Association for Osseointegration) discussed a potential introduction of such a registry process in implant dentistry as "A possible tool to further improve implant treatment and outcome" [1]. The goal was to regulate the dental implant industry and ensure quality amidst the rapid market expansion and the emergence of brands lacking proper follow-up in dental practices. Given that implant dentistry combines various components and procedures, it is crucial to scrutinize these elements in daily practice, supported by evidence-based literature, which is currently inadequate and often limited to company-provided information. The Grandview market survey showed the accelerated increase of the dental implant market, reaching U.S. $4.9B globally in 2023 [2]. It is projected that the U.S. dental implant market will reach $9.62 billion by 2030, growing at an annual rate of 9.8%. This growth is attributed to the rising incidence of dental issues and an aging population. Amidst this industrial expansion, there is increasing concern about new diseases associated with dental implants. The Grandview reports also highlight heightened regulatory scrutiny from various authorities and governmental bodies. However, despite these efforts, structured and rigorous guidelines are still lacking both within regulatory organizations and intra-dental organizations.

Recently, the European Federation of Periodontology published S3-level Clinical Practice Guidelines regarding peri-implant diseases [3]. The authors expressed concerns about peri-implant diseases, highlighting them as a significant public health issue due to their high prevalence and serious consequences, including the loss of implants and supporting prostheses. They emphasized the importance of addressing the costs from placement to management for the public, along with evidence-based risk factors and indicators for patients. Clinicians involved in implant-related therapies must recognize their ethical obligation to inform patients about potential costs, including those associated with maintenance and possible total failures of the fixtures and supporting structures.

In another study, Insua et al. discussed patient-centered perspectives on peri-implant diseases, emphasizing the concerning fact that these conditions are "poorly informed" [4]. The authors found that 74.1% of patients were unaware of peri-implant pathology until after it developed, with 32% describing the experience as terrible. Those affected by the disease had a better understanding of implant therapy compared to those unaffected, suggesting that awareness typically only arises after complications occur. This lack of prior knowledge underscores the necessity for dental professionals to educate patients about the risks of peri-implant diseases as part of the informed consent process. Such education is crucial not only for patient awareness but also for reducing potential legal issues, as seen with the increasing health-related legal cases in implant dentistry in Ontario, Canada. The logical follow-up question in this context is, naturally, "Can we fix or manage the peri-implant diseases?" Barootchi and Hom-Lay Wang [5] adhered to the definitions of peri-implant health, peri-implant mucositis, and peri-implantitis and reported that the nature of peri-implant diseases has many confounding factors and that there is no standard protocol for managing the diseases. Two years after the 2017 workshop, Group 4 focused on peri-implant diseases. Khoury et al. published a supplementary article on the surgical treatment of peri-implantitis [6]. The authors highlighted the importance of treatment strategies that focus on reducing inflammation and disinfecting biofilm on exposed implant surfaces. However, they noted that no particular treatments or products have definitively shown to be superior in preserving marginal bone levels. Additionally, concerns were raised about the potential failures of augmentation procedures, including risks such as implant loss, recurrence of disease, and the long-term progression of peri-implantitis.

2. The emergence of peri-implant diseases and the current definitions

An implant, such as a graft or device, is typically embedded within tissue. This concept has a historical background stretching back over 4000 years. Ancient history highlights the significance of maintaining a complete set of teeth. Besides the development of prostheses like the well-known removable denture for George Washington, there were genuine efforts to embed foreign materials into the human jaw. Depending on the available materials and cultural background, various materials were utilized, such as carved bamboo in China, peg-shaped gold/copper in Egypt, and seashell dental implants in Mayan culture. In Europe during the 1500s to 1800s, privileged citizens often obtained teeth from underprivileged civilians for transplantation purposes. However, these transplanted teeth likely did not last long enough to develop "peri-implant diseases" or to be documented for further investigation [7].

The modern implant dentistry took its shape and stage with a "Splendid serendipity" by a Swedish orthopedic surgeon, Per-Ingvar Branemark [8]. In 1952, while studying the blood flow in rabbit femurs, he accidentally found that a titanium device had become fused to the bone surface [9]. Titanium (Ti, atomic number 22) exists in its oxide form as a solid at room temperature, does not trigger an inflammatory response from the human or animal immune system, and osteoblasts can deposit new bone onto its surface. This pivotal discovery marked the beginning of a new era in modern implant dentistry. Since Professor Brånemark's first documented case in 1965, where he treated a patient with an atrophic mandible using four implants, various forms of research and development in implant dentistry have been observed worldwide. Furthermore, the recognition of "dental implants" as a valuable clinical measure and as an opportunity for a profitable biomedical industry was immediate and immense. In 1982, recognizing the lack of standards and systematic preclinical investigations in implant dentistry, Professor Emeritus George A. Zarb of the University of Toronto organized the first-ever conference titled "Osseointegration in Clinical Dentistry." This event brought together dental specialists, including senior academic prosthodontists and oral surgeons from North America, with 70% of the universities in the region accepting the invitation. A relatively unknown Swedish team joined them; all convened to review the systematically structured clinical data presented by Dr. Branemark [10]. Shortly thereafter, clinicians and researchers began to organize evidence-based clinical data and sought to define success. It was a bold yet crucial effort, made without their knowledge of another emerging term, "survival," in this field. To establish these criteria for success, Albrektsson et al. reviewed the published evidence on the most well-known implants in current use [11]. The list includes the subperiosteal implant, vitreous carbon implant, blade-vent implant, single-crystal sapphire implant, Tübingen implant, IMZ dental implant, Core-Vent titanium alloy implant, trans-osteal mandibular staple bone plate, and the Brånemark osseointegrated titanium implant. As outlined, there were numerous designs aimed at achieving osseointegration using different approaches. Given the variety, establishing a success criterion across multiple designs would have been a challenging task. In 1991, Smith and Zarb set out to gather the variables needed to define what success would look like in this context [12]. The criteria they proposed for evaluating implant success encompassed a comprehensive set of factors: implant mobility, the presence of peri-implant radiolucency, marginal bone loss, and patient comfort. Also included were the depth of the gingival sulcus, the health status of the gingiva, any damage to adjacent teeth, violations affecting the maxillary sinus, mandibular canal, or the floor of the nasal cavity, as well as the overall appearance of the implant. Furthermore, they considered the presence of persistent infections and the duration of service as essential indicators of success. Before this publication, three publications aimed to establish the criteria for implant success in 1979–1984 with three publications, i.e., Schnitmann and Schulman (1979) [13], Crainin, Silverbranch, Sher, and Slater (1982) [14], and McKinney, Koth, and Steflik (1984) [15]. These authors proposed mobility (less than 1 mm), radiolucency, bone loss (less than 1/3), gingival inflammation without symptoms, absence of paresthesia, and surprisingly, "Functional service for 5 years in 75% of patients" [13]. These criteria would not survive under the scrutiny of contemporary dental/governmental/public awareness and standards in 2024.

As the field progressed, it became clear that implant dentistry was not solely about measuring success but also about assessing the compromised status of implants across a spectrum, providing care for each patient even when dealing with less-than-ideal or merely surviving implants. Misch et al. refined the definitions of "implant success, survival, and failure" to provide clinicians with updated criteria [16]. They argued that the existing criteria were misleading, as they labeled symptomatic implants that remained in the mouth as "successful" simply because they were still being managed and retained. Therefore, those implants should have been labeled as "surviving" or "survived" implant(s) [17]. Naturally, the clinicians started to think of the clinical status of implants' well-being in a three-dimensional way: "clinical parameters," "patient factor," and "time." Clinical parameters typically encompass observable signs such as mobility, suppuration, and radiographic abnormalities, while patient factors involve symptoms like pain, paresthesia, and sensitivity during function. Additionally, the time factor categorizes the duration that an implant, in conjunction with a prosthetic, functions successfully—ranging from 1 to 3 years as "early" success, 3 to 7 years as "intermediate" success, and over 7 years as "long-term" success [16].

Though the term "*Peri-implantitis*" was originally used by Levignac in the French literature in 1965 [17], Mombelli et al. used the term in the English literature for the first time in 1987 in the comparison of site-specific microbiomes on the successful vs. failing implant [18]. Throughout its chronological events, the first attempt to define the disease around the implant was documented in the 1st European Workshop on Periodontology in 1994 [19]. Since the definitions of these new diseases, so-called "peri-implant diseases, i.e., peri-implant mucositis and peri-implantitis," were published, the authors collected available data to elucidate the pathogenesis of diseases, and the general direction of evidence pointed to the bacterial cause based upon the investigation in the experimentally induced peri-implant mucositis [20, 21], microbiological studies in quantitative and qualitative methods [22–24], and microbiological comparison between successful and failed implants [18, 25]. During the 2017 World Workshop, the joint collaboration of the American Academy of Periodontology and the European Federation of Periodontology added objective diagnostic measures to place the peri-implant diseases in an objective and measurable spectrum [26]. Additionally, the authors defined "Peri-implant health," "Peri-implant mucositis" and "Peri-implantitis" with case definitions for "day-to-day clinical practice" by evaluating four clinical factors, i.e., "Signs of inflammation"(SOI) + "Bleeding/suppuration on probing"(BSOP) + "Pocket depths compared to the previous visit(PDI)" + "Progressive marginal bone loss"(MBL).

- Peri-implant health: All negative clinical factors.
- Peri-implant mucositis: All positive factors except MBL with/without PDI.
- Peri-implantitis: All positive clinical factors.

One must understand that these are more diagnostic criteria for the case definitions for an everyday clinician. This may need to be modified in our biological interpretation with/without the prosthetic contribution around the peri-implant diseases.

3. Diagnosis and prevalence of the peri-implant diseases

Utilizing dental implant therapy in routine restorative dental clinics is a contemporary norm. One can easily assume the number of dental implants being employed in oral rehabilitation is increasing significantly, and naturally, the prevalence of peri-implantitis is expected to rise [27]. Previously, the fundamental problems in assessing the extent of diseases lacked a standardized threshold under the definitions of the diseases. The heterogeneity in evaluating the peri-implant was always an issue. Koldsland et al. reported a substantial range of peri-implantitis based on the degree of marginal bone level [28]. The authors investigated the prevalence using different probing depths ($\geq$ ***4mm,6mm***) ***and*** different radiographic bone loss at $\geq$ **2.0,3.0*mm***. The authors reported a total prevalence of 20.4% at the subject level and 11.4% at the implant level. However, the range was 11.3–47.3% ***with significant variance***. Even though the targeting population may increase the variability even more, the 2017 World Workshop employed Derks et al.'s report to indicate the prevalence of peri-implant mucositis and peri-implantitis ranged from 19 to 65% and 1 to 47%, respectively [29]. In their meta-analysis, the prevalence of peri-implant mucositis and peri-implantitis at the subject level was 43% and 22%, respectively. The range was wide enough to show the various case definitions being used in the literature at that time. The value to measure the heterogeneity (Inconsistency, *I*), I^2, was 94 and 97% for peri-implant mucositis and peri-implantitis, respectively. Since the 2017 World Workshop, the attempt to standardize the threshold to define diseases has become apparent. Diaz et al. conducted a systematic review and meta-analysis to assess the prevalence of peri-implantitis, noting a significant improvement in study heterogeneity [30]. The research uniquely approached prevalence measurement by considering cases both with and without probing depth, following the 2017 World

Workshop Consensus, which advised against using probing depth as a diagnostic criterion for peri-implantitis. Their findings revealed that peri-implantitis prevalence was higher when probing depth was included, at 24.69% at the patient level and 15.21% at the implant level, compared to 17.56 and 11.99%, respectively, when it was excluded. Despite the numerical insignificance of probing depth measurements, its qualitative aspects—such as bleeding, suppuration upon probing, or changes in depth—are critical for evaluating peri-implant health and establishing a baseline for ongoing assessments.

In the investigation of the prevalence of peri-implant diseases, one of the most challenging tasks is to minimize the influence of confounding factors such as diabetes, smoking, age, plaque control, conditions of periodontal status, socioeconomic status, existing co-morbidity, geographic variations, patient's understanding of the diseases, to list a few. However, it is nearly impossible to rule out their influences in such an investigation where the number of samples in each cohort is a significant factor in calculating the significance. One of the well-investigated risk factors is a history of periodontitis in the patient receiving a dental implant, along with poor oral hygiene and cigarette smoking [31]. Jervoe-Storm et al. assessed peri-implant disease in 83 periodontal patients (Stage III and IV) with Straumann implants over 5–17 years. The mean age was 64.4, with a near-even gender split. Prevalence rates were 24.1 (patient-level) and 31.7% (implant-level) for peri-implant health, 66.3 and 58.7% for mucositis, and 9.6 and 4.2% for peri-implantitis. The study's focus on a specific implant type could explain the lower peri-implantitis rates compared to other studies [32]. The prevalence may vary depending on the demographic of the patients and other factors. Marrone et al. conducted a study on 266 implants in 103 Belgian adults, identifying risk factors such as implant type, brand, and patient characteristics like age, smoking, and periodontitis [33]. They found significant rates of peri-implant mucositis and peri-implantitis, highlighting the importance of patient education and diligent care post-implant placement. As implant therapies become more common in clinical practice, ongoing dental research emphasizes the need for longitudinal studies to understand better and address the rising incidence of peri-implant disorders, underscoring the importance of discussing these risk factors during patient consultation and informed consent processes to manage potential risks effectively.

4. Pathogenesis of peri-implant disease: "The beginning"

Peri-implant health is characterized by the absence of inflammation or infection in both hard and soft tissues, ensuring that the implants function satisfactorily and maintain esthetic integrity. Various clinical factors can cause any degree of imbalance, tipping the fulcrum of the health and leading to a diseased state, so-called "peri-implant disease." The origin of the diseases may not be living bacteria after all; however, sooner than later, the ultimate initiating etiology of peri-implant disease is the host dysbiosis toward the "biofilm" [34]. In their study, Salvi et al. discussed the similarities of peri-mucositis to gingivitis and peri-implantitis to periodontitis through the comparison of experimental designs in animal and human studies and presented the similarities in the initiation of the diseases in soft tissue-limited diseases (gingivitis vs. peri-implant mucositis) and both soft and hard tissue-involved diseases (periodontitis vs. peri-implantitis) [35].

However, it is well-recognized that soft tissues respond histopathologically to biofilms in conditions such as gingivitis and periodontitis, as highlighted by Page and

Schroeder [36]. Since then, the complexity and significance of host immune system in developing and managing periodontitis showed up to be the center of the stage of periodontitis. Hajishengallis et al. revisited the Page & Schroeder model, pointing out it is not a simple infection but rather the host dysbiosis that orchestrates a series of cellular events leading to periodontal breakdown, including neutrophils function in cross-talking to the adaptive immune system [37]. While the initial stages of periodontal and peri-implant diseases may appear similar, their progression, behavior, and management differ significantly. Peri-implant diseases can quickly spiral out of control due to the host's immune response and are challenging to reverse once advanced. Unlike natural periodontium elements—bone, cementum, periodontal ligaments, and gingiva—which collectively work with the host immune system, the bioinert titanium used in implants does not trigger the immune system but can harbor various microbiomes, leading to rapid and severe breakdown. Biopsy comparisons between tissues affected by gingivitis and peri-implant mucositis show little difference in immune cell infiltration, underscoring the complex interaction between the implant materials and the biological environment [35].

At this superficial stage of disease (gingivitis and peri-implant mucositis), the host immune response may have been similar to its extent and size. However, in its investigation of the disease's reversibility of experimental peri-implant mucositis to compare with that of experimental gingivitis, Salvi et al. reported that peri-implant soft tissue showed a significantly aggressive inflammatory response to the biofilm on the peri-implant surfaces [38]. The authors observed that reversing peri-implant mucositis was challenging, noting that even after 3 weeks, the condition did not revert to its pre-experimental state and required a more extended period for management. This indicates that despite similar etiologies, peri-implant mucositis differs significantly from gingivitis in terms of its progression, pattern, and management. Compared to periodontitis and peri-implantitis lesions, Dionigi et al. reported significant differences in host responses at the cellular levels [39]. The density of neutrophils is a hallmark of the immune response of a host toward a cellular threat. To eliminate pathogens, it creates a "respiratory burst" for those pathogens, and the byproducts of this process are superoxide (O_2^-) and the reactive oxygen species (ROS) [40]. Additionally, neutrophils utilize other mechanisms, such as the neutrophil extracellular trap (NET) [41] and nitric oxide synthase (NOS), which lead to nitric oxide (NO) production [42]. The authors analyzed soft tissue biopsies from patients with periodontitis and peri-implantitis, concluding that peri-implantitis elicited more prominent and exaggerated host responses than periodontitis.

Caruac and Berglundh reported the comparative study on the biopsies from peri-implantitis and periodontitis lesions on two groups of 40 patients diagnosed with chronic periodontitis (bone loss >50% with periodontal pocket depth $\geq$ 7 mm with bleeding on probing at 4 sites) and peri-implantitis (bone loss more than >3 mm with peri-implant probing depth $\geq$ 7 mm with bleeding on probing or suppuration) [43].

They found significantly larger and more pronounced lesions in peri-implantitis compared to periodontitis (**Figure 1**). Specifically, peri-implantitis lesions displayed higher densities of vascular structures within the infiltrated connective tissue, which averaged 3.48 ± 2.54 mm^2 in peri-implantitis versus 1.49 ± 1.05 mm^2 in periodontitis. Additionally, immune cell markers such as CD138, CD68, and MPO, representing plasma cells, macrophages, and PMN cells, respectively, were found in higher densities in peri-implantitis, suggesting more intense innate and adaptive host responses. This difference raises questions about the role of distinct microbiomes in the areas around peri-implants.

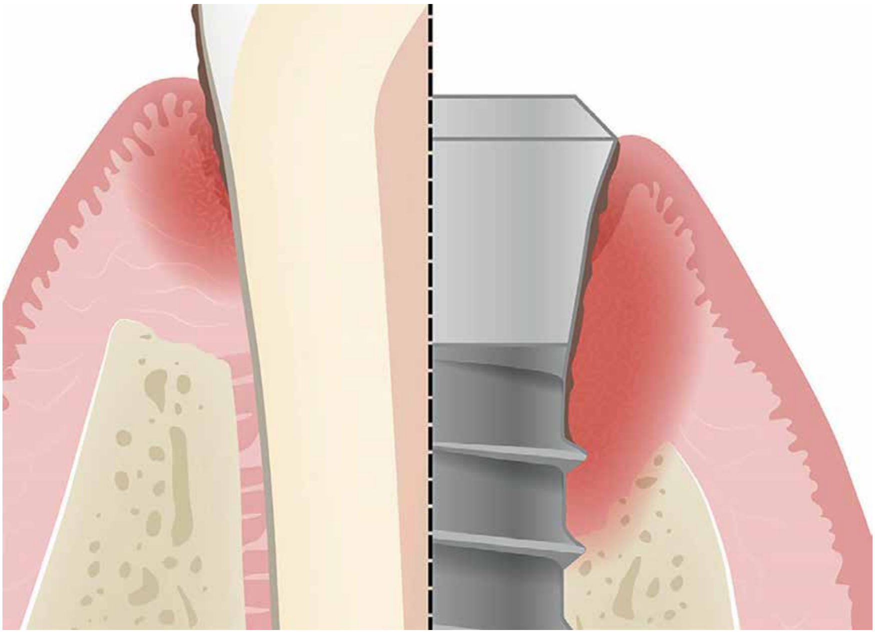

Figure 1.
The size of the inflammatory connective tissue area is larger in the peri-implant tissue compared to periodontal tissue. (illustration from [35]). According to Caracuac et al., the size of the infiltrated connective tissue area was 1.49 vs. 3.48 mm² [43].

The pathogenesis of peri-implant diseases is heavily influenced by microbiological factors, beginning with the infiltration of microbiomes that form a biofilm. This biofilm initiates an immunological cascade that, while initially protective, can lead to host dysbiosis. Traditional applications of Koch's postulates, which establish causal relationships between pathogens and disease, are not entirely applicable to periodontal diseases due to the unique and diverse microflora of the human oral cavity. Aas et al. highlighted this complexity, noting that over 700 different organisms can inhabit the oral cavity, with a single host potentially harboring more than 200 distinct types and up to 50 different organisms at one site, underscoring the distinct nature of periodontal and peri-implant diseases from other infectious diseases [44]. Culturing all microorganisms present in the oral cavity continues to be a significant challenge in dental research, and disease states can vary even within different sites of a single host's mouth. Given the difficulty in pinpointing an "active disease" site within the entire periodontium, Socransky adapted the criteria to suit periodontal disease better. His modifications include association (linking pathogens and their populations to disease), elimination (noting disease remission upon pathogen removal), host immune response (considering both cellular and humoral reactions), animal study (drawing parallels with animal models), and virulence factors (identifying unique characteristics of pathogens) [45].

Ever since it was published in 1987, Mombelli et al. explored deep (>5 mm) subgingival areas of peri-implantitis, identifying Gram-negative anaerobic rods, motile rods, and spirochetes—pathogens commonly associated with periodontitis [18]. Four decades later, advancements in biomedical technology have refined culturing techniques, enabling the identification of these diverse pathogens around peri-implant pockets. Modern methods include checkerboard DNA-DNA hybridization, 16S rRNA gene-based PCR, qPCR, and fluorescence in situ hybridization [46]. Recent research confirms that the microbiomes around the peri-implant disease are heterogeneous (mixed and variable), exhibiting a mix of various organisms but predominantly composed of Gram-negative anaerobes [47]. Furthermore, a recent systematic review and meta-analysis showed those taxa to be associated with peri-implantitis (and not associated with "non-peri-implantitis") [48]. A recent systematic review and meta-analysis identified specific taxa associated with peri-implantitis, distinguishing them from non-peri-implantitis conditions [48]. The authors concluded that peri-implantitis is associated with the presence of *Streptococcus epidermidis* (odds ratio, OR: 10.28

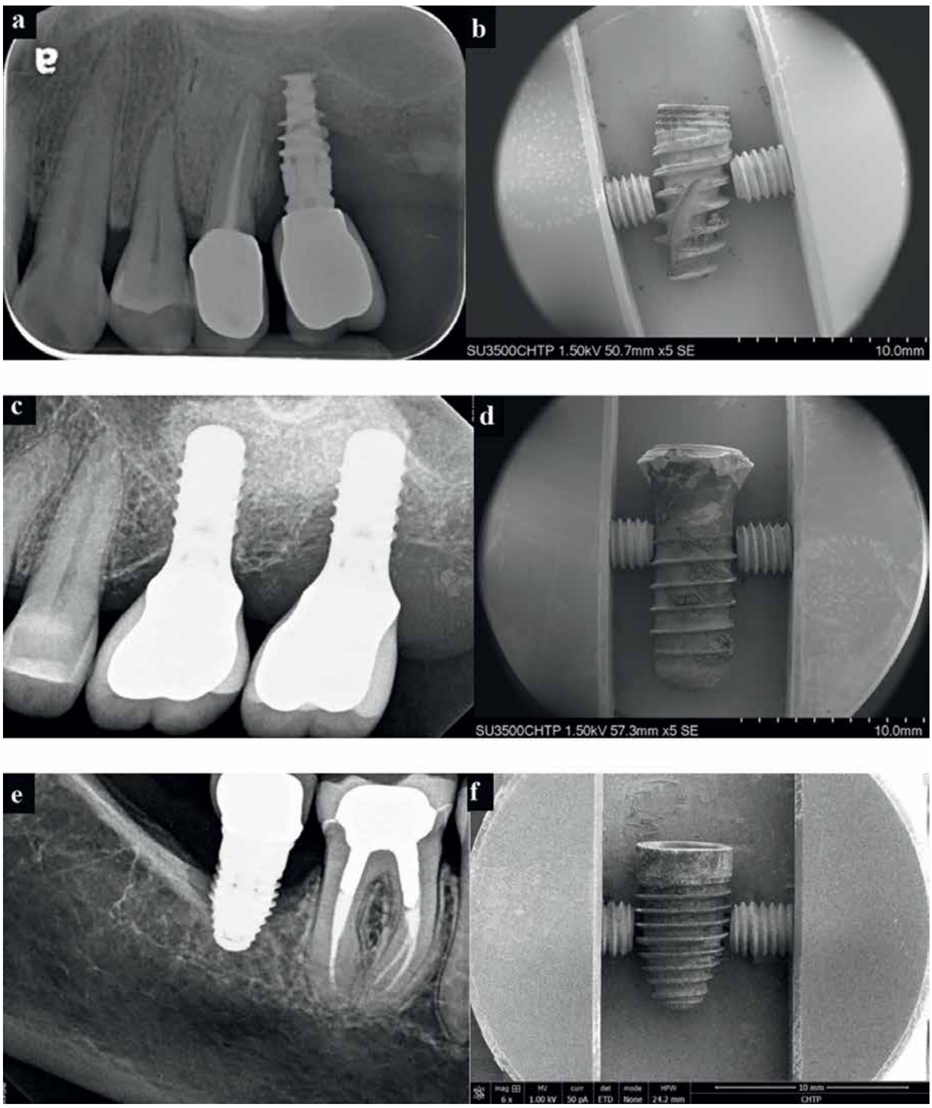

Figure 2.
Radiographic images of a set of removed implants due to severe bone loss and how they were embedded for the imaging at the scanning electron microscope [50].

[95% Confidence interval (CI): 1.26–83.98]), *Fusobacterium nucleatum* (OR: 7.83 [95% CI: 2.24–27.36]), *Treponema denticola* (OR: 6.11 [95% CI: 2.72–13.76]), *Tannerella forsythia* (OR: 4.24 [95% CI: 1.71–10.57]), *Prevotella intermedia* (OR: 3.79 [95% CI: 1.07–13.35]) and *Porphyromonas gingivalis* (OR: 2.46 [95% CI: 1.21–5.00]). Except for S.*epidermidis*, all these organisms are typical periodontal pathogens in the red and orange complexes, as categorized by Socransky and Haffajee in 1998 [49]. *S. epidermidis*, commonly associated with skin and mucosal infections that involve suppuration, presents a unique aspect in the microbiology of peri-implant diseases. This organism

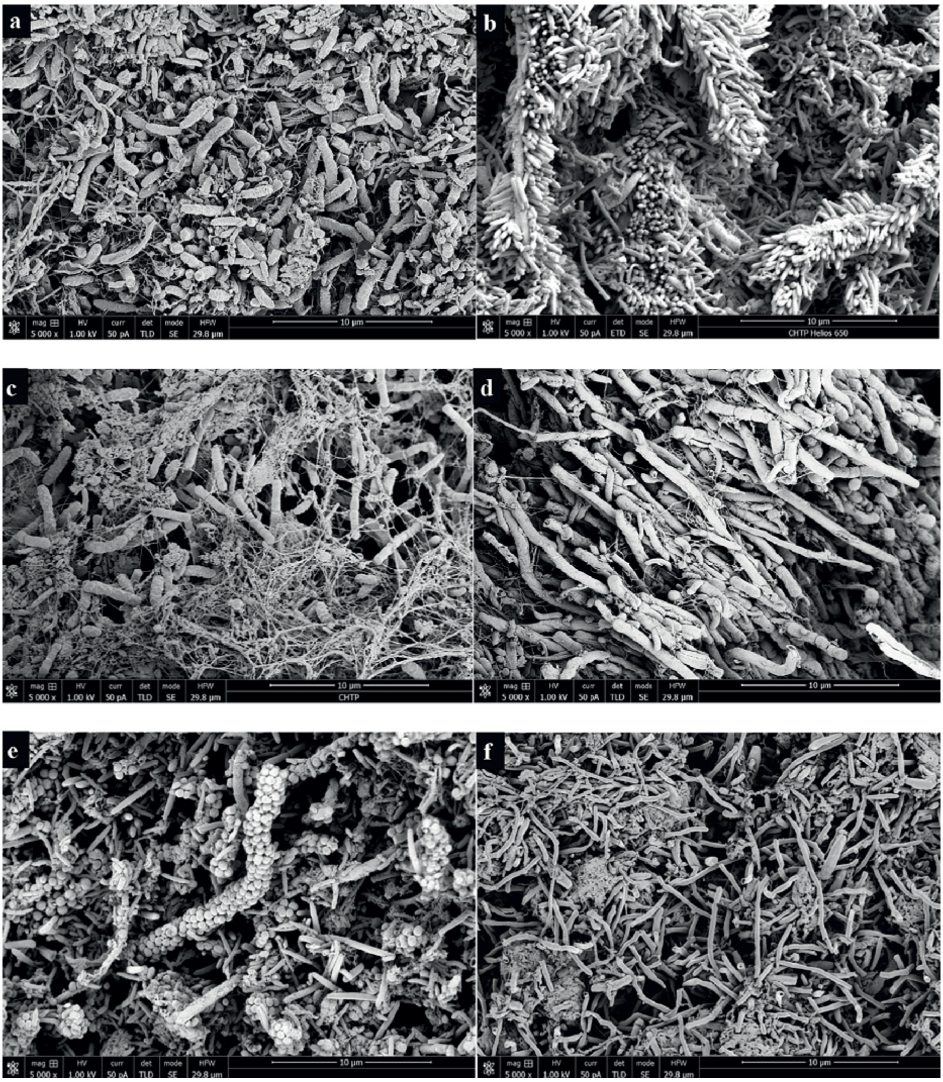

Figure 3.
High-resolution scanning electron microscopy images (5000x) on the surfaces of the failed implants. (a, b) The images of the coronal third surfaces of failed implants show abundant rods and spirochetes (a) and bristle-brush formations (b); (c, d) the images of the middle third surface of failed implants show curved rods (vibrio) with flagella (c) and rods and filaments (d); (e, f) the images of the apical third surfaces of failed implants demonstrate the presence of corncob formations with central filament coaggregation with cocci (e) and rods and filaments (f) [50].

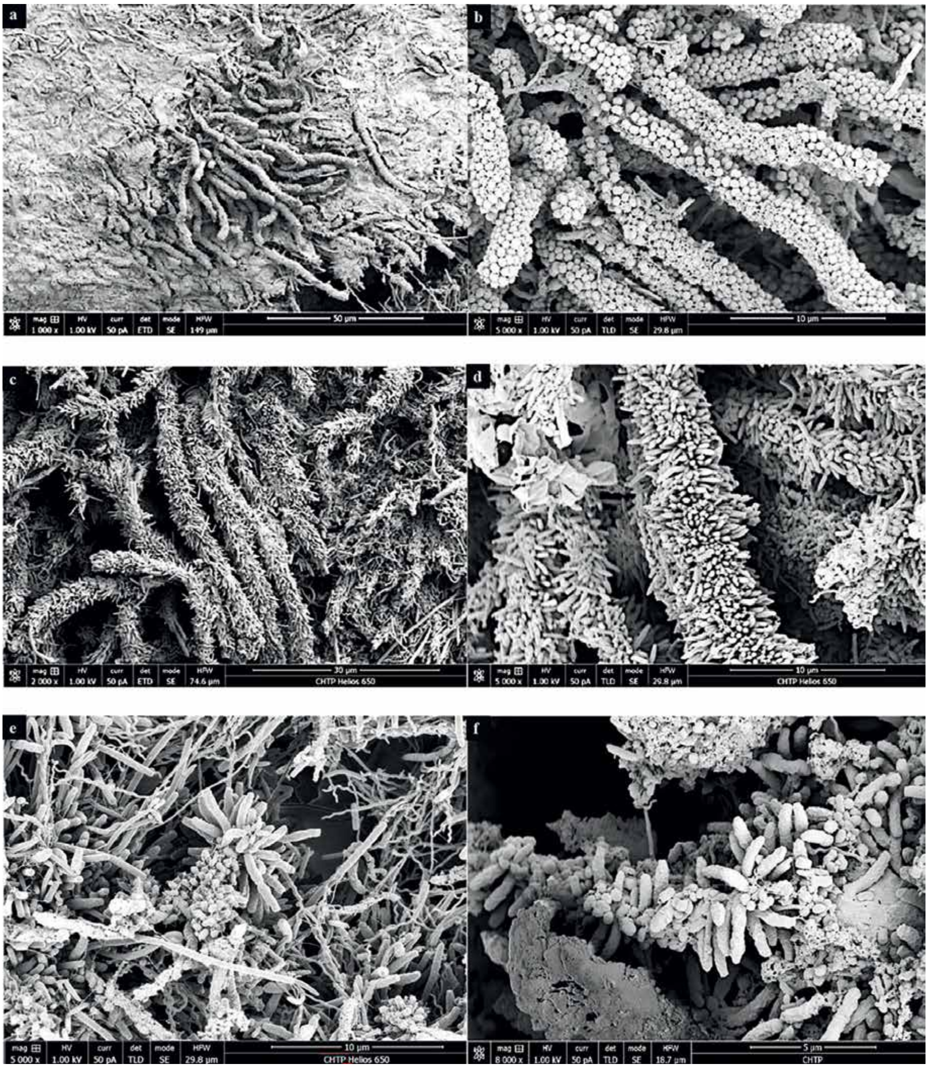

Figure 4.
Co-aggregate structures of the biofilm on the surfaces of failed implants. (a, b) Corncobs on the coronal third areas of failed implants (a, 1000x; b, 5000x); (c, d) test-tube brush formations on the middle third areas of failed implants (c, 2000x; d, 5000x); (e, f) hedgehog structures on the middle third areas of failed implants (e, 5000x; f, 8000x) [50].

is noted as an early colonizer in the formation of biofilms. Following the initial colonization by cocci morphotypes, motile rods, and long filamentous organisms contribute to creating a structural scaffold, which supports the development of a robust biofilm. Subsequently, the arrival of free-flowing spirochetes indicates the biofilm's maturity as it integrates into its structure. Later, free-flowing spirochetes arrive and infiltrate into the biofilm, showing the maturity of the biofilm. Chang et al. observed high heterogeneity in bacterial morphotypes across different clinical presentations, noting predominant forms of rods and filaments, with a concentration of cocci in the apical areas of bone loss around implant fixtures [50] (**Figures 2–5**). The collected samples, resembling Listgarten's 1979 descriptions, displayed complex microflora structures like "corncobs," "hedgehogs," and "test-tube" formations.

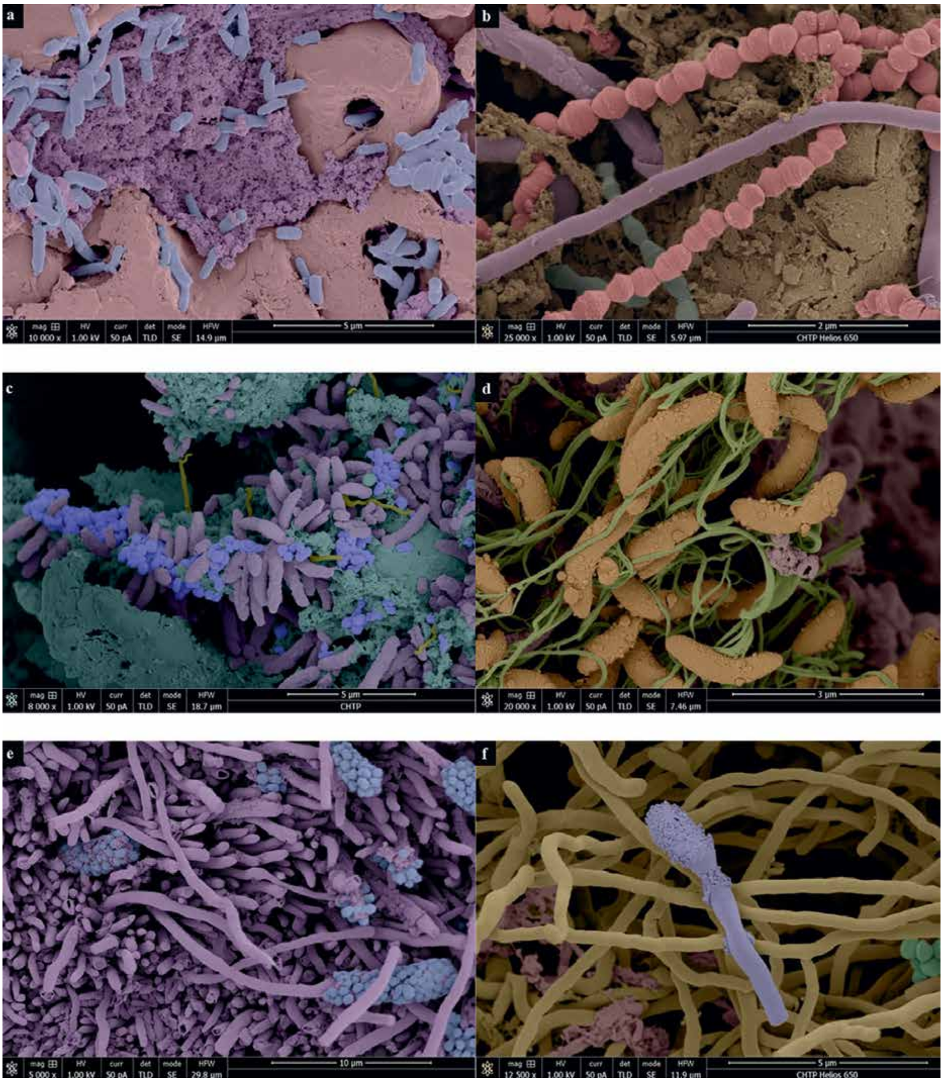

Figure 5.
Pseudo-colored scanning electron microscope images of native biofilm on the surfaces of the failed implants. (a) Rods (blue) around the pores of the anodized implant surfaces (pink; 10,000x). The matrix is colored purple. (b) Cocci (pink) along with filaments (purple) embedded in matrix (brown) (25,000x). (c) Hedgehog formation with cocci (blue) and rods (purple) around matrix (green) (8000x). (d) Morphotype of vibrio (curved rods, orange/brown) covered with vesicles and elongated fimbriae/flagella (green) (20,000x). (e) Multiple strands of the corncob formation with filaments (purple) and cocci (blue) (5000x). (f) Unknown morphotype (purple) with filamentous morphotypes (yellow), cocci (green), and matrix (pink) (12,500x) [50].

5. Management of the peri-implant diseases

There is often a latent period during which the immune system gradually mounts a defense. The first usual sign, with or without awareness of the host, would be "bleeding" of peri-implant tissue [51, 52]. The presence of peri-implant pocket depth, whether inherent from the initial implant placement or acquired through the re-establishment of the supra-crestal attachment apparatus (i.e., biological width), serves as a critical clinical parameter. Clinicians can use this measurement to identify predictive indicators of the disease's progression. Adding to this understanding, Carcuac et al. conducted a prospective longitudinal study on 73 patients with 130 implants undergoing surgical therapy for peri-implant diseases, finding that 44% of the treated implants experienced recurrence or progression [53]. Specifically, 21% of implants (27 out of 130) were removed due to failure following peri-implantitis treatment. Implants with residual pocket depths ≥6 mm had a significantly increased risk of recurrence (OR 7.4; 95% CI 2.8–19.3). Other factors associated with recurrence or progression included reduced marginal bone levels (OR 1.4; 95% CI 1.1–1.7) and modified implant surfaces (OR 5.1; 95% CI 1.6–16.5).

The management of peri-implant diseases currently lacks standardization and is hampered by the absence of long-term studies and consistent evidence [27]. The variability in clinical and radiographic presentations of dental implants, due to differences in implant placement and restorative planning, leads to diverse outcomes and a lack of consensus among clinicians, causing confusion in treatment approaches. Each implant can be considered to have its own unique "story," with individual responses influenced by site-specific characteristics and the host's condition over time. Furthermore, the progression of peri-implant diseases is significantly affected by the quality and specific response of the host's immune system, which varies between the gingiva and the peri-implant mucosa, adding complexity to their management [54]. Managing inflammation in peri-implant mucosa requires more time and effective biofilm removal compared to gingiva surrounding natural teeth. Heitz-Mayfield et al. found that at the biomarker level, it takes more than 3 weeks to reverse the clinical signs of peri-implant mucositis once the plaque control was resumed [55]. The management of peri-implant diseases is influenced by a complex interplay of factors: the implant body embedded within the bone structure, varied prosthetic planning options, different soft tissue profiles, and the unique characteristics of the host. These factors collectively can intensify the host's immune response. Additionally, the extent of surgery and systemic conditions of the host also contribute to the complexity. As a result, the clinical outcomes and durability of conventional implant-supported prostheses are inherently diverse and variable.

5.1 Nonsurgical approach

A nonsurgical approach is limited to the plaque removal of the infected implant surface with minimal efficacy. Various methods are available for managing peri-implant diseases, including mechanical and physical instrumentation with specially treated scalers or air-polishing devices. Additionally, thermal and photodynamic approaches such as lasers, as well as chemical treatments using a range of agents with or without antibiotics, are employed [56]. In the nonsurgical approach, a resorbable chitosan brush was introduced that may be applied during the maintenance program. These chitosan fibers are gentle enough to be used on the tooth surface as well as the exposed implant surfaces without damaging the root or titanium surface.

In a 12-month follow-up study, Khan et al. conducted a multicenter randomized clinical trial involving 31 patients with dental implants [57]. The study directly compared the effectiveness of the chitosan brush with that of a titanium scaler for mechanical debridement, finding no significant differences in the clinical parameters measured. Finally, the effectiveness of using systemic or local antibiotics along with probiotics in conjunction with standard nonsurgical maintenance treatments was explored [58]. Systemic antimicrobials improved the pocket depth and degree of bleeding upon probing. However, the application of the local antibiotics showed a lesser extent of clinical benefit.

5.2 Surgical approach

The goal of surgical intervention around peri-implantitis may differ depending on the severity/extent of the lesions at the time of intervention. Ideally, the goals of surgery are to restore the surrounding peri-implant architecture, which includes: (1) cleaning and disinfecting the previously exposed implant surface, (2) restoring optimal marginal bone levels, (3) eliminating residual peri-implant pocket depth, (4) ensuring the absence of host responses such as pain, discomfort, or signs of inflammation (i.e., no bleeding, suppuration, erythema, or edema) in the peri-implant soft tissue, and (5) achieving a healthy soft tissue profile with keratinization to create a seal around the implant-abutment junction, along with sufficient supra-crestal attachment apparatus (biological width) to support ongoing peri-implant therapy. Karlsson et al. evaluated the effectiveness of access flaps in eliminating peri-implant pockets and managing peri-implantitis across 16 articles [59]. The meta-regression analysis revealed that each millimeter increase in baseline pocket depth resulted in an average reduction of 0.7 mm in pocket depth, with a 27% reduction in bleeding on probing.

There was also a slight average gain of 0.2 mm in marginal bone levels. The study highlighted a shortage of comparative research between nonsurgical and surgical therapies for peri-implantitis, noting that pocket reduction surgery using an open-access flap approach was effective. However, frequent recurrence and eventual implant loss were significant issues. New technologies are continuously evolving to manage peri-implantitis, particularly in the decontamination of infected or exposed implant surfaces. Among these, an electrolytic method was introduced, utilizing the Galvosurg device (GalvoSurg Dental AG, Widnau, Switzerland) with or without Airflow Plus Powder (Airflow, EMS, Nyon, Switzerland) [60]. Schlee et al. reported promising results from an 18-month randomized controlled clinical trial involving 24 patients. After replacing the restorative parts and following a closed healing protocol, significant reductions in pocket depth and gains in bone were observed post-surgical intervention for peri-implantitis.

5.3 Prevention

European Federation of Periodontology published the “Clinical Practice Guideline” on the prevention and management of peri-implant diseases [3]. The authors divided the levels of prevention into four levels, starting from the primordial prevention (“before implant placement”) to primary prevention (“prevention of disease onset/control of risk factor”), to secondary prevention (“prevention of disease recurrence”), to tertiary prevention (“prevention of disease complication”). The authors highlighted that the presence of a dental implant inherently increases the risk of peri-implant diseases, eliminating the possibility of “primordial prevention” after placement. Three key elements were identified as essential for primordial prevention of peri-implant diseases.

1. Patient factors (systemic health, including periodontal health and its history and plaque control ability)

2. Site factors (osseous morphology and soft tissue profile for proper implant placement and its longevity/stability)

3. Prosthetic factors (micro-gap, Implant-Abutment Junction (IAJ)/restorative margin, good access for oral hygiene aids/maintenance, facilitating optimal plaque control)

The authors stressed the importance of considering maintenance and peri-implant disease prevention early, including in prosthetic design for optimal plaque control, emphasizing the complexity of managing peri-implant diseases once they occur (**Figure 6**). Martins et al. noted in their systematic review that while surgical intervention is often required for managing peri-implantitis, the outcomes are notably unpredictable [61]. The dental implant community has evolved from a bone-driven approach in the 1990s to the early 2000s to the current paradigm of "Prosthetically driven implant placement," supported by advancements in guided bone regeneration for ideal prosthetic function and esthetics [62].

Well-accepted phenomenon of marginal bone loss (remodeling) after the connection of the prosthesis may need to be perceived as a threat for future progressive bone loss (not just as a "foreign body reaction") over time due to the presence of putative pathogens within/near the implant-prosthetic complex [63]. In this book chapter, I would like to introduce the term "*Maintenance-Driven Implant Dentistry*" for the first time ever, as per my knowledge, to emphasize the critical element in long-term success ultimately lies within the prevention of biofilm formation understanding the peri-implant diseases being opportunistic in nature. The easy and effective maintenance regimen from both a professional and patient's perspective around the implant-prosthetic complex sites potentially harboring the biofilm, i.e., micro-gaps, restorative margin, and any local factors such as cement and exposed implant rough surfaces, must be warranted.

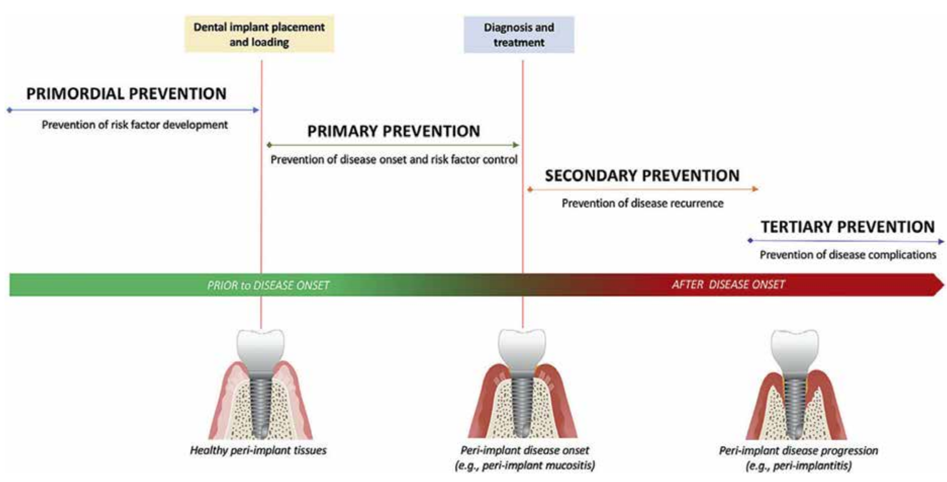

Figure 6.
Regardless of health status of an implant, the primordial prevention phase is active for every implant. However, once placed, primordial prevention cannot be applied. Therefore, it cannot be reversed [3].

6. Reality check: Cost-effectiveness of the diseases'

There are only a few studies that investigated the cost-effectiveness of peri-implant disease therapy. Listle et al. surveyed 40 periodontology specialists in Germany to assess the cost-effectiveness of eight nonsurgical peri-implantitis treatments over 12 months, measured by cost per millimeter of peri-implant pocket depth (PPD) reduction [64]. Debridement alone was most cost-effective for budgets under €5/mm, followed by AirFlowTM (5–384€), debridement with PerioChip® (384–781€), and debridement with local antibiotics (exceeding 781€/mm). While providing valuable insights for clinicians, these findings have limitations and should be interpreted with caution. Additionally, costs have likely risen since 2015, with nonsurgical methods sometimes matching the efficacy of surgical interventions, which generally achieve greater bone gain, as demonstrated in Wagner et al.'s study [65].

Schwendicke et al. explored peri-implantitis management, including surgical interventions, in a similar study [66]. Using a Marklov model, the authors simulated 20 years of follow-up with/without supportive implant therapy aimed at managing peri-implant mucositis and preventing peri-implantitis. Findings indicated that while nonsurgical treatments without SIT were the least costly, they were also the least effective. Conversely, the most effective treatments, involving bone grafting and laser therapy, cost 56 euros per 1% reduction in implant loss, highlighting a significant difference in implant loss rates with SIT (21%) versus without (64%). The study underscores the complexity and variability in the cost-effectiveness of managing peri-implant diseases, with no definitive standards and often unpredictable expenses. Thus, the best approach is to prevent the onset of peri-implant diseases from the planning stage to avoid these complications and associated costs.

7. Spectrum of peri-implantitis: 'Till the endpoint, it is "The Battle Zone"'

Clinically, peri-implant diseases have various subclinical or clinical presentations. An implant fixture with mild marginal bone loss may have strong, soft tissue expression with erythematous and edematous status, whereas another implant has a significant dehiscence defect with minimal to zero expression of inflammation. Sometimes, soft tissue may mislead a clinician by masking the existing bone loss (dehiscence or fenestration defects around the implant) until a certain moment of flare-up, showing slow at the beginning but rather into rapid transition to more acute, erythematous expression with/without rapid bone destruction in time. Therefore, one can conclude that peri-implant diseases may have a steady-state or continuous yet non-linear pattern of progression. Furthermore, a silent site may harbor those key pathogens in peri-implant tissue [67] to shift the microbiome to cause host dysbiosis, which is considered a tipping point for an imbalance and breaking point of the steady state, triggering a strong host inflammatory cascade. Therefore, it is unique in the sense that it can be a silent, asymptomatic disease for a certain period.

During this period, a clinician may alert the patient with close monitoring and a more meticulous maintenance program. As stated by the European Federation of Periodontology, with the clinical practice guideline, there are four stages where risk factors could be reviewed and assessed, the primordial stage being the most ideal. However, not all implants show their risk factors at the beginning, and/or there

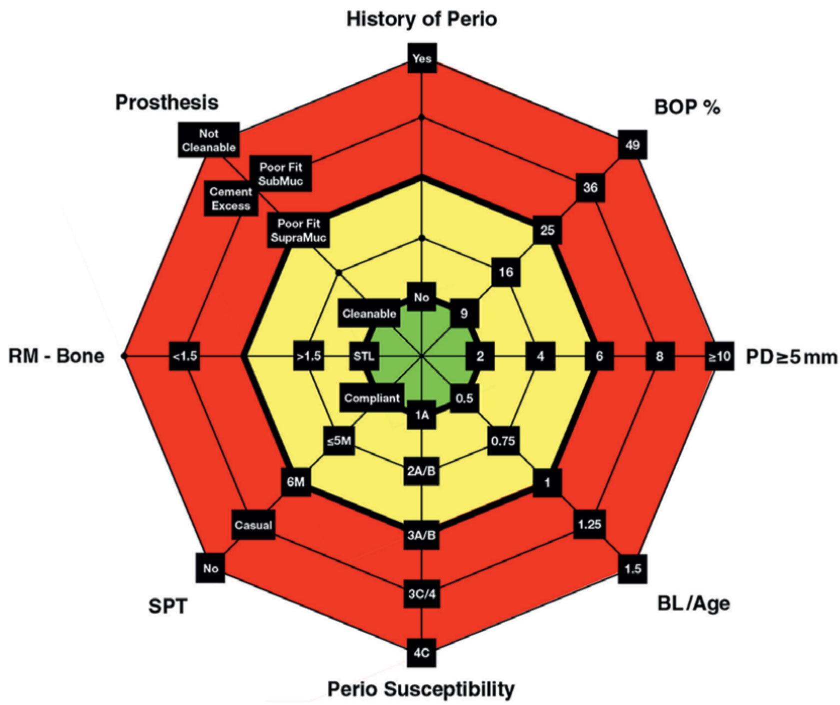

Figure 7.
Implant Disease Risk Assessment (IRDA) [67].

may be a period of the host revealing his/her own risk factors/indicators afterward. Many factors may or have already predisposed the implants to manifest peri-implant diseases. Heitz-Mayfield et al. organized those known factors into a vector system to assess the risks in a visual diagram (**Figure 7**) [68].

In its tips of an octagon, there are proposed risk indicators with categorical variables depending on the severity of such risk indicators.

Quantifying the risks of peri-implant diseases is possible using specific diagrams, but management protocols lack strong evidence, with treatment outcomes influenced by host and local factors. This variability results in subjective clinical approaches and inconclusive research findings. Chang et al., using scanning electron microscopy, observed surprising cellular activities on failed implant surfaces, offering new insights [50]. The authors observed cellular interactions resembling a "battle" between immune cells and invading microbiomes, suggesting the immune system acts

1. History of periodontitis: Yes/No
2. Full mouth BOP% score: 9–16–25-36-49%
3. Number of pocket depth ≥ 5 mm: more than 2–4–6-8-10 sites
4. Bone loss % (most severe site)/Age: 0.5–0.75-1.0-1.25-1.5
5. Peri-implant supportive therapy: Every ≤ 5 M, 6 M, Casual, Never
6. Depth of restoration: Soft tissue level - ≥1.5 mm - ≤1.5-Bone level
7. Prosthesis-related factor: Cleansable - Poor fit to supra or submucosa/excess cement—Not cleansable

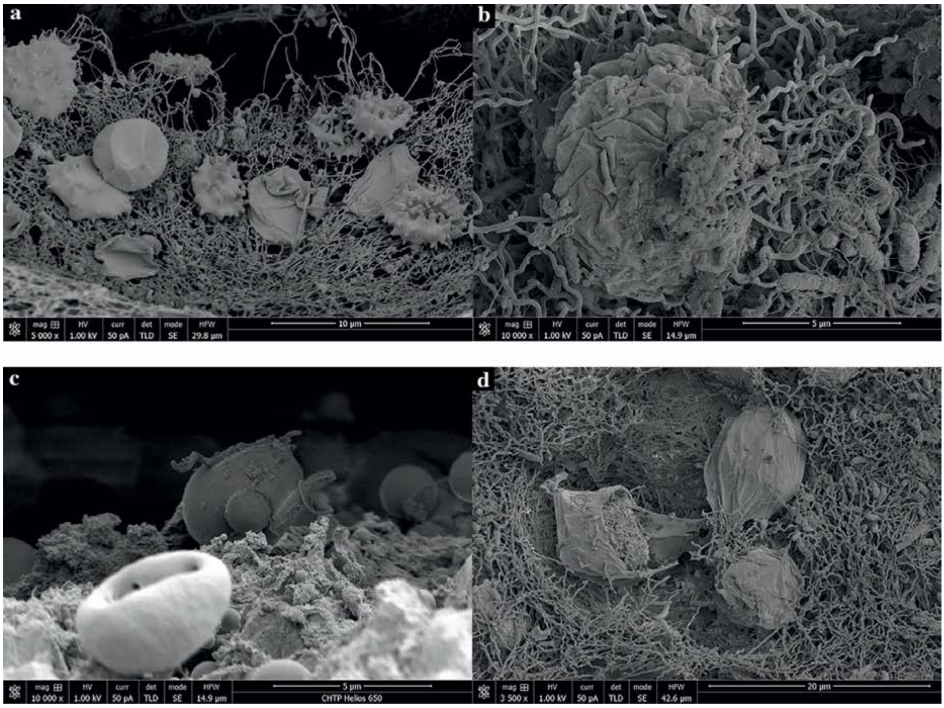

Figure 8.
Different cellular activities captured during the investigation (a) Various cells mixed with microbiomes. (b) A cell is surrounded by spirals and rods. (c) Some dead cells have perfect holes and some spiral and cocci attached to the surface of the cell membrane (d). Three cells attached together surrounded by an overwhelming number of spiral bacteria, and one of them exposed inner content to the environment.

more as a defensive alarm than an aggressive attacker, though the images' authenticity remains uncertain (**Figure 8**).

8. The current dental education on the implant dentistry

The discussion on peri-implant diseases highlights gaps in dental education, particularly at the undergraduate level, which pose challenges in managing these conditions. Generational differences and varied access to continuing education, from free courses to expensive programs, further contribute to this issue. Meanwhile, the roles of dental specialists and general dentists are expanding to include complex implant procedures, such as soft tissue grafts and zygomatic implants. Although the implant industry offers training programs, these often prioritize product promotion over comprehensive education [69]. It was well-accepted by dental students, and there were more demands on this educational protocol, which included supervised procedures. There were earlier attempts to implement implant education at the undergraduate level at the Albert-Ludwigs University, Freiburg, Germany, in 2011 [70]. Their curriculum included 64 hours of seminars with hands-on sessions along with clinical experience. Compared to the one from OHSU, these undergraduate students were eligible to place and restore oral implants under prosthetic-driven planning with 3-dimensional imaging and guides. The prosthetic components restored by an undergraduate student varied from a single-unit crown to multi-unit fixed prosthesis and overdenture cases. Their implant survival rate was 98.9%, and therefore, this was comparable to those of experienced clinicians. They concluded to promote the inclusion of oral implantology to be part of the undergraduate curriculum.

Another conundrum is to define the scope of dental implant education. As a guideline, a clinician must be able to assess his/her own clinical experience/ability based on the "Straight, Advanced and Complex" classification [71]. Mattheos et al. evaluated European guidelines for undergraduate implant dentistry education, recommending that straightforward cases be included in the curriculum while emphasizing the importance of distinguishing them from more complex cases. They identified challenges such as curriculum crowding, faculty shortages, increased costs, and patient recruitment issues, complicated by competition with graduate programs. In Canada, specifically Ontario, the level of undergraduate exposure to implant education varies, with the Royal College of Dental Surgeons of Ontario regulating educational requirements based on whether clinicians focus on surgical, prosthetic, or both aspects of implant dentistry [72]. The guideline emphasizes the importance of periodical review by the Royal College of Dental Surgeons of Ontario due to the dynamic nature and rapid advancements in the implant dentistry. There are detailed requirements in the hours of continuing education, including initial educational requirements, educational requirements for complex cases, and ongoing educational requirements. Throughout the appendix sections of the guideline, there are five checklists, from the pre-surgical checklist to long-term follow-up and maintenance. There may be a need for an additional checklist regarding peri-implant maintenance protocol.

Discussion of peri-implant diseases should be a mandatory part of the initial consultation phase in dental care, clearly communicated to and understood by both clinicians and patients. Insua et al. highlighted this need by reporting that a significant majority (74.1%) of patients, out of a study group of 135, were unaware of peri-implant pathology, underscoring the importance of education and transparency in implant dental therapy [4]. The patient's awareness of peri-implantitis was low, and a pertinent question arose: do general practitioners truly understand peri-implantitis? However, Thomas et al. reported, in a quantitative study using a questionnaire in the United Kingdom, that this may not be the case [73]. In this study involving 224 dentists, those with 10–20 years of experience showed greater awareness of diagnostic criteria for peri-implant diseases compared to their less experienced or more seasoned peers. However, only 34% had received prior training in implants. Notably, 13% of practitioners avoided probing during routine examinations due to concerns about surface damage, infection risk, legal implications, and uncertainty about what to look for or how to assess the situation. This underscores the urgent need for enhanced educational initiatives at the undergraduate level to equip dentists with the skills necessary to diagnose and intervene in peri-implant diseases early in their careers.

9. Conclusion: "Tomorrow with clinical uncertainties"

The exponential global increase in dental implant placements has led to a rise in peri-implant diseases, presenting diverse challenges influenced by clinical, patient-specific, and site-specific factors. Accurate diagnosis and identification of the root causes of these diseases are considered critical for minimizing clinical uncertainties, which are exacerbated by current limitations in understanding. It is recognized that education programs in implant dentistry require enhancement, not only to cover surgical and restorative phases but also to include comprehensive management responsibilities. The boundaries between dental specialties and general practitioners in implant dentistry are becoming less distinct due to advancements in technology and the increased availability of continuing education platforms. This accessibility has allowed nearly any dental clinicians regardless of their experience levels or clinical interests, to engage in implant therapy, often without sufficient training.

To address these challenges, a paradigm shift is being proposed toward "*Maintenance-Driven Implant Dentistry*"*—a concept that emphasizes planning implant therapy with cleansable, maintainable implant-prostheses, prioritizing long-term peri-implant tissue health while accounting for systemic, site-specific, and local patient factors.* This approach seeks to expand on and refine the current "Prosthetically Driven Implant Dentistry" model, which primarily focuses on achieving prosthetic success. By shifting focus to peri-implant tissue health and maintenance, this new concept aims to create implant-prostheses that are both functional and sustainable over time, truly integrating disease prevention into implant therapy. Although peri-implant diseases may never be fully eradicated, advancements in technology, public awareness, and education are expected to significantly reduce their prevalence. Future research should prioritize innovative solutions, such as developing biofilm-resistant surfaces, minimizing reliance on extensive bone regeneration through 3D printing and customized implants, re-evaluating historical methods like subperiosteal implants, optimizing soft tissue management, and emphasizing the retrievability of implants for long-term care. Additionally, increased public and professional education on peri-implant diseases and stricter regulation of practitioners involved in implant therapy is essential to ensure consistent and high-quality care.

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This comprehensive book provides a holistic examination of oral health, highlighting its crucial role in overall well-being. Bridging clinical practice with contemporary research, the book highlights the essential connections between oral care and systemic health, demonstrating how oral conditions can influence general health. Readers will find valuable insights into preventive dentistry, including effective strategies for caries control, the use of fluoride, and patient education, alongside advances in restorative techniques that enhance clinical outcomes. The volume also addresses pediatric oral health, early interventions, craniofacial anomalies, and orthodontic considerations, underscoring the importance of early care and developmental dentistry. Furthermore, it provides an overview of oral cancer detection and management, offering guidance on early diagnosis and treatment. With a focus on integration and best practices, this book serves as an indispensable resource for dental professionals, healthcare providers, and anyone interested in the vital interplay between oral, systemic, and public health. Its broad scope, practical insights, and up-to-date perspectives make it an essential reference for advancing oral health care in clinical and community settings.

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