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Dental Caries
Diagnosis, Prevention and Management

Edited by Zühre Akarslan

DENTAL CARIES - DIAGNOSIS, PREVENTION AND MANAGEMENT

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Dental Caries - Diagnosis, Prevention and Management
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Contributors

Lubna Tahir, Rabia Nazir, A. Zeynep Yildirim-Bicer, Senem Unver, S. N. Goryawala, R. Ebru Tirali, Çağdaş Çınar, Ceren Deveci, Gamze Metin Gürsoy, Fatma Deniz Uzuner, Laurence Walsh, Arzu Pinar Erdem, Abeer ElEmbaby, Zühre Akarslan

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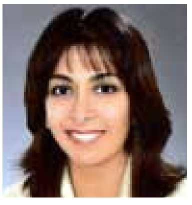

Zühre Akarslan was born in 1977 in Cyprus. She graduated from Gazi University Faculty of Dentistry, Turkey in 2000. She received her PhD degree from the Oral Diagnosis and Radiology Department of the same university in 2007. She became a Professor in 2018 and is working as a full time lecturer and an academic researcher. She has published research in various international and national journals, edited a book, written book chapters, and she serves as an editorial board member and reviewer of several scientific journals. Her expertise areas are dental caries, cancer, dental fear and anxiety, gag reflex in dentistry, oral medicine and dentomaxillofacial radiology. She is married and has two children.

Book Series Editor and Editor of Volume 1: Zühre Akarslan
Gazi University Faculty of Dentistry, Turkey

Scope of the Series

The major pathologies which dentists encounter in clinical practice include dental caries and periodontal diseases. Diagnosis and treatment of these pathologies is essential because when untreated, abscess could occur and it can even lead to the extraction of the tooth. Extracted teeth can be replaced with implants. Dentists and patients are nowadays more familiar with dental implant treatments. As a result, advanced diagnostic tools which aid in pre-operative treatment planning (cone-beam computed tomography, computer aided implant planning etc..), new implant designs improving the success of osteointegration, new materials, and techniques are introduced in the dental market.
Conditions which dentists frequently encounter in their clinical practice are temporomandibular joint (TMJ) disorders. These disorders include degenerative musculoskeletal conditions associated with morphological and functional deformities. Accurate diagnosis is important for proper management of TMJ pathologies. With the advance in technology, new materials, techniques and equipment are introduced in the dental practice. New diagnostic aids in dental caries detection, cone-beam computed tomographic imaging, soft and hard tissue lasers, advances in oral and maxillofacial surgery procedures, uses of ultrasound, CAD/CAM, nanotechnology, plasma rich protein (PRP) and dental implantology are some of them. There will be even more new applications in dentistry in the future.
This book series includes topics related to dental caries, dentomaxillofacial imaging, new trends in oral implantology, new approaches in oral and maxillofacial surgery, temporomandibular joint disorders in dentistry etc.

Contents

Preface

Dental caries is a major health problem affecting many individuals worldwide. It develops in the presence of bacteria, biofilm, and carbohydrates. Oral hygiene has an important role in the development of the disease. Ancient civilizations were aware of the importance of oral hygiene, and they used several applications to remove the dental plaque. Although humans took such measures, this was not sufficient for the total elimination of caries. The prevalence of caries increased with the global increase in sugar consumption. Thus, communities started to make additional preventive strategies. These strategies were based on the modification or elimination of the factors leading to caries and application of remineralization agents.

Caries prevalence decreased over time with these preventive measures; nevertheless, many people are still affected from the pathology and require dental treatment. For the successful treatment of caries, a correct diagnosis of the pathology is required.

The visual-tactile method and radiographic imaging are the conventional techniques used for the detection of dental caries. With progress in technology, adjunct methods, such as laser fluorescence and quantitative light fluorescence, have also been developed.

After a carious lesion is diagnosed, an appropriate treatment decision should be made for the management of the pathology. There is a shift toward early diagnosis of the lesions and control of the disease at the initial stage.

In this book, readers can find a current overview of the subjects addressed above. Hopefully, it will serve as a practical handbook for the treatment of caries.

I would like to thank all the authors, Ms. Anita Condic, and all the staff who took a role in the production of this project. I would like to thank my family, my husband Veysel, and my sons Utku and Uğur for their patience during the preparation of this book.

Professor Zühre Akarslan
Department of Oral and Maxillofacial Radiology
Gazi University Faculty of Dentistry
Turkey

Chapter 1

Introductory Chapter: Diagnosis of Dental Caries

Zühre Akarslan

Additional information is available at the end of the chapter

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Introduction

Dental caries is a frequently observed pathology affecting both the primary and the permanent teeth. This disease is usually detected with visual-tactile method. Visual-tactile method is suitable for the detection of cavitated caries localized on the occlusal and smooth surfaces of the teeth. It also gives diagnostic information about the presence of deep cavitated caries localized on the approximal surfaces. However, it is not useful for the detection of initial non-cavitated approximal caries. It is not useful for the detection of initial non-cavitated approximal caries.

After the discovery of X-rays, radiography has become a routine method for the detection of dental caries. Caries causes loss of hard tissue of the teeth, therefore appears as a radiolucent area on radiographic images. The radiographic appearance of enamel caries is generally a radiolucent triangle. This changes when it progresses into the dentine. It is frequently seen as two triangles, one on the enamel, and the other on the dentin, with a base on the dento-enamel junction [1].

Compared to visual-tactile method radiographic imaging is superior for the detection of caries confined to enamel and dentine, and minimal cavitated lesions on approximal surfaces [2]. It has a higher sensitivity for detecting lesions extending into dentine and lesions forming cavitations on the approximal surfaces of the tooth. On the other hand, compared to visual-tactile method, the sensitivity of radiography for detecting initial caries is lower, but its specificity is higher. Detection of initial caries is important as they can be treated with non-invasive or micro-invasive methods, such as remineralization, sealing, or infiltration [3].

Periapical, bite-wing and panoramic radiography are routinely used two-dimensional radiographic techniques for the detection of caries. With the introduction of three-dimensional imaging in dentistry, it became possible to detect caries from cone beam computed tomography images. However, compared to intraoral and panoramic radiography, the radiation dose of this technique is very high; thus, it is not routinely used [4].

The crown, the root and the surrounding structures of the tooth in the area of interest could be assessed with periapical radiography. In general, periapical radiography should be performed in cases having deep dentinal caries and when the periapical region is going to be investigated. The crowns of the teeth and part of the roots (excluding the periapical region) in the area of interest could be evaluated with bitewing radiography. This technique allows the visualization of both the maxillary and mandibular teeth crowns in one radiographic image. In addition, due to the projection geometry, initial caries could be more visible compared to the periapical and panoramic technique. Bite-wing radiography is the most useful technique for the detection of caries [1].

Bite-wing radiographs could be obtained with intraoral X-ray equipment or with panoramic machines having a extra-oral bitewing option. These panoramic machines have a special digital sensor and a robotic motion of the panoramic X-ray tube. The advantage of this imaging modality is that it reduces the number of overlapping areas of the teeth compared to conventional panoramic radiography. However, the cost of the equipment is very high, and the number of false positive findings is higher [5].

According to the literature, compared to visual inspection bite-wing, radiography has a higher sensitivity for the detection of dentinal caries localized on the approximal surfaces [6]. However, it does not provide adequate information in all patients having caries located on the inner surface of the enamel and cavitated or non-cavitated lesions located on the outer surface of the dentine [7]. In general, the use of both visual-tactile method and bite-wing radiography increases the possibility of the detection of caries as compared to those using either method alone [8].

Although two-dimensional intraoral imaging is useful and has several advantages for caries detection, superimposition of unwanted structures is the main disadvantage of this method. In addition, the cervical burn-out effect and parallax phenomena seen on the approximal surfaces of the teeth are factors leading to false positive results [9]. Correct detection of caries is important as this is the key for proper treatment. Thus, the dentists should consider the advantages and disadvantages of these methods in dental practice.

The chapters in this book provide rich information to the readers starting with the history of oral hygiene manners, and modern oral hygiene practices. It continues with the prevalence and etiology of dental caries and remedy through natural sources. Etiology of secondary caries in prosthetic restorations and the relationship between orthodontic treatment and caries is addressed. Early childhood caries is presented according to updated research. The use of visual-tactile method, radiography and fluorescence in caries diagnosis is presented. The book ends with prevention methods and management of caries and white spot lesions.

Overview of the chapters of this book.

Second chapter: 'Vista of Oral Hygiene' written by Goryawala S. This chapter gives information about evolution and teeth. The author provides interesting history of oral hygiene manners of various ancient civilizations. The importance of oral hygiene habits for the prevention of caries is stressed. The relationship between pregnancy, radiotherapy to the oro-facial region, and caries is presented. The chapter ends with information about modern oral hygiene practices.

Third chapter: 'Dental Caries, Etiology and Remedy through Natural Resources' written by Tahir Lubna and Nazir Rabia. This chapter starts with the prevalence and etiology of caries. The role of dental plaque and microbiol flora in the development of caries is described. The authors give informative details about the usage of synthetic and herbal products for the treatment of caries. The readers could also find the answer for the question 'Why the dentists should go for natural resources in medicine?' according to the literature.

Fourth chapter: 'Etiology of Secondary Caries in Prosthodontic Restorations' written by Yıldırım Biçer A. Zeynep and Unver Senem. This chapter starts with the etiology and diagnosis of secondary caries. Detailed information about the factors affecting microleakage, marginal and internal fitting of the prosthetic restorations are presented. The authors' description of contemporary fabrication methods including Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) systems and cementation agents based on recently published data is particularly informative.

Fifth chapter: 'The Relationship between Orthodontic Treatment and Dental Caries' written by Metin Gürsoy Gamze and Uzuner Deniz. This chapter starts with general information about removable and fixed orthodontic appliances and their effect on accumulation of dental plaque. The authors emphasize the importance of proper oral hygiene habits required for struggle against microbial agents leading to caries during removable and fixed orthodontic treatment. They underline the importance of daily removal of the dental plaque on the teeth and describe useful mechanical, chemical and biological methods for this purpose.

Sixth chapter: ' Early Childhood Caries Update' written by Pınar Erdem Arzu. This chapter starts with the diagnosis and classification of early childhood caries according to contemporary literature. Detailed information about the epidemiology and etiology of this pathology is provided. Prevention strategies from early childhood caries are given. The chapter carries on with the management methods used in dental clinics for cavitated early childhood caries.

Seventh chapter: 'Caries Diagnosis Aided by Fluorescence' written by Walsh Laurence. This chapter focuses on the role of fluorescence in the diagnosis of caries. The author gives information about fluorescence in detail. Clinical recommendations for using fluorescence as an aid to caries diagnosis are particularly helpful to the readers. The author emphasizes that fluorescence may be used to improve caries diagnosis according to a rich literature review.

Eighth chapter: 'Can Dental Caries Be Treated?' written by Elembaby Abeer. This chapter describes several recent approaches used for the non-invasive management of non-cavitated teeth. Beneficial information about the remineralization agents including, laser active fluoride, low-level laser therapy, bioactive materials and natural substances are given. The readers can find an answer for the question 'Can dental caries be treated?' and benefit from practical strategies.

Ninth chapter: 'Management of White Spot Lesions' written by Deveci Ceren, Çınar Çağdaş, and Tirali R. Ebru. This chapter starts with the prevalence and etiology of white spot lesions and continues with detailed information about the diagnosis and differential diagnosis of these lesions. Preventive measures and management of white spot lesions based on recently published data in the literature are presented as well. The authors provide photographs showing step-by-step management of white spot lesions, which are useful for the readers in clinical settings.

Author details

Zühre Akarslan

Address all correspondence to: dtzuhre@yahoo.com

Faculty of Dentistry, Department of Oral and Maxillofacial Radiology, Gazi University, Ankara, Turkey

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Chapter 2

Vista of Oral Hygiene

S. N. Goryawala

Additional information is available at the end of the chapter

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Abstract

For maintaining good general health, good oral hygiene is very important. Nature gave some instinct to all animals for that. Man, since his existence, has been 'aware' of maintaining oral hygiene. Avoiding dental infections was most important for ancient man to avoid malnutrition and eventual death. Initially, man managed it through his instinctual dietary habits. Later the nature of diet and dietary habits changed and it was needed to practice some extra measures. A protocol for good oral hygiene changed from just dietary measures to chewing various materials and use of early dentifrices to modern toothbrushes, modern dentifrices, and other measures including professional intervention. Oral hygiene is more important during some specific situations in life, for example, pregnancy and certain sickness.

Keywords: hygiene, oral hygiene, history of oral hygiene, importance of oral hygiene, oral hygiene tools, oral hygiene practices

1. Hygiene and oral hygiene

Hygiene includes 'cleanliness', but it is much more than just 'cleanliness'. According to World Health Organization (WHO), 'Hygiene refers to conditions and practices that help to maintain health and the prevent spread of diseases' [1].

Therefore, many things are included in 'hygiene' like cleanliness of one's body, dwelling and surrounding area, sanitation, hygienic food, safe drinking water, clean clothing and so on.

Personal hygiene involves the care of one's body so that infections and diseases are prevented and one enjoys a feeling of being well. One of the important aspects of personal hygiene is 'Oral Hygiene'.

Mouth being one of the gateways of body, demands to be well guarded, so that entry of unwanted elements in the body is prevented. That is why good oral hygiene becomes essential. WHO also stressed on the importance on oral hygiene by declaring 'Oral Health for a Healthy Life', its theme on world health day (April 07th), in the year 1994 [2].

1.1. Evolution and teeth

We know that life appeared on earth before approximately 3.8 billion years [3]. Life at that time was primitive. Evolution is a continuous process, which has produced complex life.

During evolution, some creatures developed teeth and some did not, depending upon their requirement for food and to be selected by the Nature to survive. It is said that teeth developed in jawed vertebrates, but few different opinions are also voiced [4]. Most of the mammals have teeth. There are very few groups of mammals, who do not possess teeth and they include pangolins and anteaters.

The incidence of dental diseases in animals living in the natural environment is less, as compared to pet animals. This is because of their unrefined and fibrous food, which does not contain refined sugars. Their saliva may have alkaline pH, which reduces the incidence of dental caries.

Similarly, people during ancient times did not need too much oral hygiene because they did not consume refined sugar. It has been observed that ancient cavemen although lacking in oral hygiene, had a full set of teeth and very low incidence of dental disorders. This is because their diet was mostly natural and unprocessed fruits, vegetables, and meat [5].

Most mammals are diphyodonts, means they get two sets of teeth. Humans (*Homo sapiens* Sapiens) are also diphyodonts and get two sets of teeth, that is, deciduous (Primary or Milk dentition) and permanent (Succedaneums dentition).

In humans, the presence of teeth, though very essential, makes maintaining oral hygiene slightly difficult, due to some reasons. Inter-dental areas and pits and fissure morphology of teeth favor retention of food particles. Also, food consumed by modern man is mostly refined, soft, many times sticky, and many times have a moderate quantity of fermentable carbohydrates. Micro-organisms grow in retained food particles to produce gingival and periodontal diseases, and dental caries; if oral hygiene is not maintained properly.

2. History of oral hygiene maintenance

History of procedures adopted for maintenance of oral hygiene and preventing oral and dental diseases, and even treating oral and dental diseases can be traced as back as the time of Homo neanderthalensis and Cro-Magnons (early *Homo sapiens*), that is, about 40,000 years before, when they co-existed for almost 5000 years in Europe. Interesting is the fact that in fossils, resinous substances (such as the gum Arabic that is used in chewing gum today, and other types of sap) with tooth marks in them have been found, and dated to the time of Homo neandarthalensis and Cro-Magnons. Ancient *Homo sapiens*, and also Homo neanderthalensis appear to have used gum for chewing [6].

People of most of the major ancient civilizations were concerned about oral hygiene, and prevention and treatment of dental diseases. It is interesting to know about the level of their awareness about dentistry and oral hygiene.

2.1. Mesopotamian civilization

According to Kara Vavrosky, [7] oral care was very important to the Assyro-Babylonian culture. Assyro-Babylonians have mentioned about halitosis and mobile teeth in their literature and given over 100 prescriptions for the care of mouth and teeth. Sufferers of halitosis were advised to wash their mouth and teeth with a finger bound with cloth. To remove deposits and stains people were advised to scrape teeth with a bare finger. This remained the common teeth cleansing method for people of the region until the introduction of the toothbrush by the Chinese at the end of the fifteenth century.

A mouthwash-containing mint, storax (a fragrant balsam obtained from the bark of an Asian tree of the witch-hazel family), rue, myrrh, and salt was used for rinsing. Toothpicks played an important role in dental hygiene for the Assyro-Babylonians. Excavations have discovered vanity sets made of gold, silver, or bronze that included toothpicks along with tweezers and ear-scoops [7].

Galbanum resin, obtained from roots, and trunk of a Persian tree was used by them for massaging on gums of "loosened tooth." Naturopaths believe that galbanum inhibits microbial (fungal or bacterial) growth in the wound area in bits of help in faster healing.

2.2. Ancient Egyptian civilization

Egyptians had detailed knowledge about the human anatomy because, for mummification of bodies they performed, they had to drain blood and remove organs, which made them understand the basic human anatomy [8]. Information about the treatment and healing of oral wounds are present on the Edwin Smith surgical papyrus. The exact time is not known but this papyrus is written sometime before 3000B.C. It gives detailed information about the treatment of oral problems; however, researchers think that at that time actual pathologies associated with teeth were considered as untreatable [9]. Minor dental work was performed, and more complex procedures were developed slowly as time passed. The earliest evidences of performed dental surgery were between 3000 and 2500B.C. and generally involved drilling out cavities or pulling teeth. Egyptians by 1550B.C. had prescriptions for dental pain and injuries. Surprisingly, use of artificial teeth has not been found in literature or in mummified bodies: though ancient Egyptians are known for their wisdom and style [10].

Documents regarding awareness about oral hygiene, during ancient times in Egypt, are not enough; and many skulls recovered from mummies or excavations, show considerable amount of deposition of calculus on various surfaces of teeth. Though most of Egyptians traditionally considered general hygiene very important; and females as well as males, used many cosmetic items for their daily cleaning, anything like a toothbrush has not been found among various cosmetic items they used. Possibility has been shown that some chewing items were consumed by ancient Egyptians for mouth refreshment.

Priests chewed natron pellets (a mineral salt found in dried lake beds, consisting of hydrated sodium carbonate) as a purification ritual, and the general population, on occasions, also did so before a meal. Perhaps something resembling a miswak, which is a twig, of the salvadora persica tree, with frayed ends, might have been used. Miswak is used for oral care by Islamic traditions [11, 12].

The results of the numerous studies of the dentitions of ancient Egyptians also indicate that oral health was poor; and with little evidence of dental care, infection, and dental pain must have been widespread [13–16].

2.3. Indus valley civilization and ancient Indian civilization (Harappan and Vedic civilizations)

Indus valley civilization existed between 3300 and 1700B.C. probably a draught caused the collapse of the civilization. And later was followed by Vedic civilization in the region of the Indian subcontinent.

Study of Indus valley civilization has suggested, of dentistry being practiced 5000 years B.C. The practitioners of that time treated dental disorders with bow drills.

During the Vedic period, ayurveda, the Indian system of health care developed. Two original textbooks, “Charak samhita” and ‘‘Sushruta samhita” are considered as its basic texts. “Shalya-chikitsa,” an important branch of ayurveda, includes dentistry along with other surgeries.

Variety of chewing sticks known as “Datun,” which were and are used as an ayurvedic or herbal material for oral hygiene, are obtained from certain trees like babool (*Vachellia nilotica*), neem (Azadiroxtha indica), mango (*Mangifera indica*), and guava (*Psidium guajava*). Some other natural and herbal products, which are used in ayurveda for preventing and treating dental diseases are clove, turmeric (Curcumin longa), amla (Emblica officinalis or Indian gooseberry), *aloe vera*, garlic (*Allium sativum*), ginger (*Zingiber officinale*), guggul (Indian Bdellium gum) and so on [17].

A study carried out in the western part of India, by Goryawala S N et al., in 2015–2016, showed that 7% of the study participants used ayurvedic toothpaste and 3.5% used ayurvedic tooth powders. It was also observed that 3.1% of the participants used datun or chewing sticks [18].

Oil pulling is also suggested in “Charak samhita,” which is called “kabla graham” or “kabla gardoosa.” It has been used extensively as a traditional Indian procedure for years to prevent dental decay, halitosis, bleeding gums, cracked lips, and for strengthening teeth and gums [17]. Dr. F. Karach re-introduced the practice of oil pulling in 1990 in Russia [19]. Sesame seed oil is used most commonly because of its medicinal properties and health benefits. Sometimes, sunflower oil is also used. Oil is retained in the mouth for a defined duration of time and then spitted off. The exact mechanism of the action of oil pulling is not known.

2.4. Ancient Chinese civilization

There were many dynasties in ancient Chinese civilization (2070B.C.–1912A.D.)

The oldest medical is book known in China, "Nei Ching" (the laws of medicine), includes two chapters about a toothache and gum diseases. It also recommends gargling and gum massage. Chinese also used acupuncture and moxibustion for treating dental pain [20].

A paste made of musk and a ginger powder was frequently used in ancient China, for the purpose whitening teeth. Ancient Chinese people used their nails, a piece of wood and knife to clear remnants of food from their teeth. They used arsenic to treat decayed teeth. Chinese developed a sort of silver amalgam for filling more than 1000 years before, during Tang Dynasty [20].

Modern toothbrush with the bristles perpendicular to the handle was invented by the Chinese in the fifteenth century, mostly in 1498. The design of the brush was a handle, which was made from bone from an ox or a bamboo, and the hard bristles were made of hair obtained from the neck of a hog. In 1938, Dupont de Nemours, designed "Doctor West's Miracle Toothbrush," which had nylon bristles. Till then, use of boar bristles was most common [21].

2.5. Andes civilizations and mesoamerican civilizations (mainly Maya, Inca, and Aztec civilizations)

The Mayan civilization had developed in regions of central and South American countries of today. It began in about 750–1000 years B.C. and lasted almost up to 1697A.D., till the fall of Nojpeten, the last Mayan city.

One of the Spanish conquistadors, Hernan Cortes (1485–1547), was impressed by the advanced level of dentistry he found in the 'New World' of three cultures, the Maya, Inca, and Aztec. Hernandez, a Spanish physician, in the sixteenth century, found that the Aztecs had been obsessed with oral hygiene, bad breath, and tooth decay. Those ancient dentists filled cavities, extracted teeth, and removed tartar with copper instruments. Amazingly, after a dental procedure was performed, they used to make their patients rinse their mouths with a saline solution. He also found those people treating various dental conditions with natural medicines. They were good in treating gum diseases; oral inflammations tooth decay, bad breath, and fever blisters. They used alum as a cosmetic treatment to make teeth look whiter. Aztecs designed and extensively used toothpick which they called 'netlantataconi'. They used what they called as 'chicle,' an unsweetened gum, for cleaning teeth, and for prevention of dental caries [22].

British Dental Association's museum exhibits specimens of teeth, which are said to have been found from Mayan civilization. Mayans were excellent in dental procedures, which they used to perform for religious rituals and also for oral health and ornamental purposes.

Inlays carved from colored precious stones were placed into cavities prepared in vital front teeth, without traumatizing the pulp. Those inlays made of a variety of minerals of beautiful colors, including jadeite, iron pyrites, hematite, turquoise, quartz, serpentine, cinnabar, and gold, were ground to fit exactly into the cavity [23].

In Mexico City Museum complete skulls can be seen with all the front teeth with colorful inlays.

It is interesting to note that Andes and Mesoamerican civilizations also built pyramids like Egyptians.

2.6. Etruscan and roman civilizations

Etruscan people were the first to take basic work in the mouth to a more artistic level. Etruscans were incredibly intelligent people, who were always striving to increase their knowledge and improve themselves. Luxury was important to them. They were merchants and traveled through land and sea as a part of their profession. They acquired some knowledge of dentistry, during their trade tours, and attempted gold filling restorations. They also tried to make prosthodontic replacement of missing teeth around 700B.C., believed to be the first-ever, using gold bands, and human and animal teeth [24].

Romans gave much importance to cleanliness and style. Celsus (c 25B.C.–c 50A.D.), insisted that citizens wash their mouths in the morning. They mostly did not use the toothbrush, some formulas to make toothpaste has been described by them. The ingredients they suggested to make toothpaste include bone powder, eggshell powder, pumice, myrrh and so on.

2.7. Greek civilization

Most of the physicians and dentists in Greek civilization, up to and including Hippocrates (460–370B.C.), were members of the sacerdotal caste of asklepiadi. Ancient Greek scholars Hippocrates and Aristotle (384–322B.C.) wrote extensively on dentistry, including eruption patterns of teeth, treatments of decayed teeth and gum disease, tooth extractions using forceps, and using wires to stabilize loose teeth and fractured jaws. The Greeks recommended and used mint, a preferred ingredient in toothpaste even now [24]. Many of medical and dental advice written during this period appear to be simple medical prescriptions similar to those recorded in Egypt.

2.8. Phoenician civilization

Phoenicia was an ancient civilization in Canaan, which covered most of the western, coastal part of the fertile crescent of Syria and Lebanon of the present time. This civilization existed from approximately 1550B.C.–300B.C., when it was conquered by Alexander the Great. Later the region was governed by Egyptians and Romans. This culture known for the spread of alphabets consisted mainly of traders. Phoenician dentistry was influenced by contemporary Egyptian dentistry, which they expanded by techniques of splinting of loose teeth and replacement of missing teeth with artificial teeth made up from ivory and supported and fixed with help of gold wires [25].

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3. Importance of oral hygiene

A tooth is an organ, which is supported and held in its position by supporting tissues of gingiva, periodontal ligament, and alveolar bone. It is interesting to note here that more than 700 species or prototypes of micro-organisms are found in oral cavity, [26] which when finding an opportunity, may initiate dental caries, periodontal or other in infections in the mouth. Not maintaining good oral hygiene leads to invasion by micro-organisms, which cause infection. Thus, teeth or supporting tissues get infected. Therefore, basically microbial dental diseases are either dental caries or periodontal infections, which may lead to many complications of different types and severity if not treated.

Dental caries begins with demineralization, and re-mineralization can repair the damage; if proper conditions of repair are fulfilled. Once protein matrix of enamel collapses, the lesion becomes irreversible and a cavity is formed, re-mineralization cannot repair it. Restoration is to be done. Endodontic treatment is warranted, if there is involvement of pulp. Pulp infection may spread to the periapical region and its further spread may cause infection of various perioral spaces and may cause Ludwig's angina.

Similarly, gingival and periodontal infections can damage alveolar bone and may lead to loss of teeth. Untreated periodontal infections may cause trismus and other complications.

Negligence of oral hygiene may cause complications as severe as septicemia, toxemia, pyemia, cavernous sinus infection, bacterial endocarditis, and so on.

3.1. Oral hygiene and pregnancy

There are certain factors, which play their role during pregnancy and may cause dental and periodontal problems. Hormonal changes during pregnancy may cause gingival and periodontal diseases, including pregnancy tumor or pyogenic granuloma or granuloma gravidarum. Craving for more carbohydrate during pregnancy may cause dental caries if oral hygiene is not maintained. Demineralization of calcified tissues may increase, if there is the regurgitation of acids from the stomach, in case there is morning sickness.

For many reasons, dental procedures are avoided during first and third trimesters of pregnancy, unless special considerations and precautions are observed. Pharmacologists, obstetricians, pediatricians, and also FDA of USA advise not to administer medicines having teratogenic effects and many other drugs during pregnancy. It is also wise to avoid dental radiography during pregnancy, though there is just minimal radiation and even if abdomen and thyroid are shielded from radiation. Benefits and potential risk must be taken into consideration, while prescribing medicines and radiography during pregnancy.

Microbial infection from mother may get transmitted to her unborn child and may cause premature birth, low weight baby, and infection of the baby.

Considering these facts, it is recommended that pregnancy is planned, and thorough oral prophylaxis and other required dental treatments are done before, and nice oral hygiene is maintained during pregnancy and also thereafter.

3.2. Oral hygiene as related to pre and post radiotherapy of oro-facial regions

Many times radiotherapy is prescribed after onco-surgery for treatments of malignancies of the oro-facial region. Radiotherapy reduces salivary flow and produces xerostomia. It also makes bone ischemic and hypoxic. Xerostomia may lead to dental and periodontal infections, if oral hygiene is neglected. If extraction of a tooth is needed and carried out, healing may get complicated due to the ischemic and hypoxic condition of the bone. There are chances that osteo-radio-necrosis may develop. It becomes mandatory to maintain oral hygiene for cases of radiotherapy.

3.3. Other considerations about oral hygiene

Immunologically compromised persons need to be more vigilant about an oral hygiene.

Patients who have undergone a surgery or a procedure in an oral cavity, should also maintain good oral hygiene to allow rapid, better, and uncomplicated healing. Similarly, those suffering from systemic disease need to pay more attention to maintain oral hygiene so that their recovery does not get complicated by oral infections. Some systemic conditions like diabetes mellitus, hormonal imbalance, viral infections, thrombocytopenia, leukemia and so on may predispose to oral diseases. Some systemic conditions, or medicines used for their treatment, may cause xerostomia.

4. Modern oral hygiene practices

Currently available tools for oral hygiene include the following:

4.1. Dentifrice

Dentifrice is a material, which may be in form of powder, paste, or gel and is used for cleaning natural teeth. As it is noted, many different prescriptions have been given to formulating a dentifrice since ancient time. Use of dentifrice became common since nineteenth century. Most preferred form at present is toothpaste. Earlier, toothpastes were available in jars and were known as “dental creams.” At present, they are available in convenient collapsible tubes. A modified design of nozzle of a tube can be used for striped or layered toothpaste.

Ingredients of a dentifrice (toothpaste):

4.1.1. Abrasives

They constitute almost 50% in composition and are insoluble fine particles of different silicas, which cause minimal enamel erosion; and remove plaque and to some extent calculus and stains.

4.1.2. Surfactants

Detergent or sodium lauryl sulfate (SLS) is used to reduce surface tension to allow the spread of paste on the tooth surface. SLS may alter the perception of taste for certain short period of time after using toothpaste.

4.1.3. Anti-microbial agents

Many anti-microbial agents can be a part of toothpaste, but most common is triclosan at present. Its use is controversial and debatable.

4.1.4. Fluorides

Fluorides are believed to play important role in the prevention of dental caries. Usual concentration of fluorides in toothpaste remains between 1000 and 1500 ppm. Sodium fluoride (NaF), stannous fluoride (SnF_2), Di-sodium mono fluoro phosphate ($Na_2PO_3F_2$) and so on, may be included.

4.1.5. Flavoring, sweetening, and coloring agents

Common flavoring compounds used are menthol, peppermint oil, and spearmint oil; but many others are also used. Bubblegum flavor is used in toothpaste made for kids. Not flavored toothpastes are also available.

Sometimes ingredients used in toothpaste provide color to it, and there is no need to add additional coloring agent.

Sweetening agent used, must obviously not be sugar, and also must be non-toxic.

The ingredients of a dentifrice are mixed with glycerol, sorbitol, xylitol, or similar compound to give it the form of a paste.

Various medicated toothpastes are also available, and they are mainly used to provide relief from dentinal sensitivity. The compounds used for this purpose, act by plugging exposed dentinal tubules. Desensitizing toothpastes contain one or more of the substances such as stannous fluoride, sodium mono fluoro phosphate, amine fluoride, calcium carbonate, arginine bicarbonate, calcium sodium phospho silicate (Novamin or BioGlass), casein phosphopeptide (CPP), amorphous calcium phosphate (ACP), nano-hydroxy apatite, strontium acetate and so on.

Potassium nitrate when used provides short-lived relief from symptoms of dentinal sensitivity. It acts through the mechanism of conduction of nerve impulse.

Various tooth whitening pastes contain abrasive to remove stains and carbamide peroxide in different concentrations to act as a bleaching agent. Such pastes must be used under the professional guidance and not for a prolonged period to prevent damage to the enamel of teeth.

Herbal or natural dentifrices are also available, which do not contain chemicals like sodium lauryl sulfate (SLS) or fluorides. They contain natural compounds like eucalyptus oil, clove oil, plant extracts and so on.

Nicotine (Tobacco) containing toothpaste, which is available in India and some other Asian countries are actually habit forming, hazardous, and stain teeth. Their use must be avoided.

4.2. Toothbrush

A brush for cleaning teeth has been used since the use of chewing sticks. After stick was chewed, its end became brush-like and was used as a toothbrush.

Modern toothbrush having bristles perpendicular to the handle was first made by Chinese people at the end of the fifteenth century (1498) [20]. The material used for bristles and also handle kept on being changed and modified as time passed. Initially for bristles, hairs from pig's back or tail and for the handle, an ox bone or bamboo were used. Other materials to be used for bristles were horse hairs, badger hairs, Siberian boar hairs, porcupine quills and so on. For handles wood, ivory, and also gold were used.

First mass production of toothbrushes was done by William Addis of Clerkenwell, London, England, in around 1780 [27]. H. N. Wadsworth became the first American to patent a toothbrush (patent number 18653) on November 7, 1857 [28].

Toothbrushes with nylon bristles and plastic handle were designed by Dupont de Nemours in 1938 and were made popular by American army during Second World War as American soldiers were advised to use these brushes [27]. Size and shape of head and handle of a toothbrush may vary. Sometimes, it is claimed that certain angles in the design of handle of a toothbrush help to guide the head to the areas difficult to access. Consideration should also be given to the belief that basically, it is the movement of the wrist of the user, which guides the head to different areas of the dental arch.

Squibb and Sons Pharmaceuticals of America launched first electric toothbrush in the market in 1959–1960, under the name, 'Broxodent' [29]. Many brands of the powered toothbrushes are available at present and they are of more help to physically compromised persons. Many varieties of the powered toothbrush are available.

The purpose of using a toothbrush along with toothpaste is to remove plaque and debris from surfaces of teeth, to provide a gentle massage to gingiva and to suppress halitosis. A toothbrush should be having soft bristles and should be used with a scientific brushing technique, so as to prevent damage to gingiva, and avoid abrasion of cervical enamel and cementum.

Specially designed brushes are also available to clean inter-dental areas and are used for maintaining gingival health.

4.3. Tongue cleaners

Tongue cleaners available at present may be boilable, made up of stainless steel, or plastic material, which can withstand high temperature or disposable. Various toothbrushes also may have a tongue cleaner on another side of the head where bristles are located. Many times soft toothbrush itself may be used to clean tongue.

Tongue cleaners remove debris from the dorsal surface of the tongue and prevent fungal infection.

4.4. Dental floss

Threads and rags, which were used in old times for cleaning proximal surfaces of teeth, have become dental floss. Dental floss available at present is basically mounted or unmounted waxed silk thread, which may be flavored.

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4.5. Mouth washes

Mouth washes have also been used since old times and many formulae have been suggested from time to time.

Rinsing the mouth removes loose debris from teeth and mouth and, depending upon the composition of the solution used, may perform some other task. If it is an antiseptic mouth wash, it reduces the number of oral micro-organisms.

If a mouth wash contains fluoride, it may help prevent dental caries or may sooth symptoms of dentinal sensitivity. Flavored mouth washes provide a feeling of refreshment.

4.6. Some other tools for oral hygiene

Sugar-free gums when chewed, stimulate salivary flow and help in maintaining neutral pH in an oral cavity.

Toothpicks (of proper material and design) are useful for removal of food lodged interdentally if used properly. Water jets may be used for maintaining periodontal health during orthodontic treatment and even otherwise. Plaque disclosing solutions help in efficient removal of plaque. Caries detection solutions are also available for early detection of dental caries.

The following may be recommended to maintain good oral hygiene.

Minimum twice a day brushing of teeth, using a soft toothbrush and good toothpaste, which may be fluoridated if needed, with recommended scientific brushing technique, should be done.

Daily dental flossing should be done for cleaning proximal areas.

Fluoridated or other mouth washes should be used if recommended.

Sugar-free gum may be chewed to stimulate salivary flow, for maintaining neutral pH in an oral cavity.

Regular dental checkups and prophylaxis should be performed by the professional consultant. Orthodontic treatment can be executed to relieve crowding of teeth, which may cause food lodgment and initiate a disease.

The balanced diet is essential for maintaining good general as well as dental health.

5. Conclusion

Mankind, since its existence has been concerned about oral hygiene. Maintaining good oral hygiene is one of the important tools to remain healthy.

Conflict of interest

There is no conflict of interest.

Author details

S. N. Goryawala

Address all correspondence to: dr_goryawala@yahoo.in

Department of Dentistry, GMERS Medical College, Vadodara, India

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Chapter 3

Dental Caries, Etiology, and Remedy through Natural Resources

Lubna Tahir and Rabia Nazir

Additional information is available at the end of the chapter

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Abstract

Caries and oral mucosal and periodontal diseases are the major cause of oral health problems. They are prevalent in all ages and demographic and socioeconomic groups. Irrespective of geographic location in the world, both males and females are affected from the condition. Dental caries' etiology has four main factors: bacteria, time, susceptible tooth surface, and fermentable carbohydrates. Due to the high prevalence of oral disease and increased microbial resistance against antibiotics, there is a need for alternative methods. Therefore, the search for viable alternative products is of paramount importance. Phytochemicals isolated from plants, which are used in traditional medicines, are considered to be safe and effective alternatives compared to synthetic chemicals. This situation diverted efforts toward finding natural products as the potential medicine for treating dental caries. The chapter will focus on the etiology of dental caries and different remedies using the natural resources for prevention and treatment of the disease. A wide variety of secondary metabolites in medicinal plants having in vitro antimicrobial activities provide a hope for novel drug compounds.

Keywords: dental caries, etiology, natural resources, bacteria

1. Introduction

1.1. Dental caries

Oral diseases, a major health issue in the world [1], are economically affecting people of developed countries as 10% of the health expenditure is related to dental care. Even though there is an improvement in oral health in most of the developed countries, there are still dentally disadvantaged people, usually with low socioeconomic status [2].

1.2. Prevalence in the world

Caries and oral mucosal and periodontal diseases are the major oral health problems in developing countries [3]. They are prevalent in all ages and demographic and socioeconomic groups. Irrespective of geographic location in the world, both males and females are affected from the condition. Dental caries is most prevalent in Latin America, South Asia, and the Middle East and least common in China [4]. Dental caries increase with age due to denture use and poor hygiene. The presentation of caries varies among people, but the risk factors and developmental stages are the same [5]. According to a survey by the National Health and Nutrition Examination Survey (NHANES) in the United States (1992–2004), conducted among adults between 20 and 64 years old, there was a decline in cases up to 97% in the 1990s, but still the prevalence is high, affecting 92% of people. In developing countries, this percentage rose to 96% [6]. Oral diseases like tooth loss, oropharyngeal cancers, dental caries, oral mucosal and periodontal diseases, and HIV/AIDS-related oral diseases are the main public health problems globally [1, 7]. Out of total 291 diseases and injuries evaluated in global burden of disease, untreated tooth decay has the highest rate of prevalence between 70 and 90% of populations [8], and it is also one of the most common reasons for tooth extraction.

2. Etiology of dental caries

Caries is a chronic, multifactorial disease, which causes destruction and demineralization of hard tissues of teeth by acid production occurring from bacterial fermentation of food [9]. **Figure 1** represents the common factors involved in caries formation.

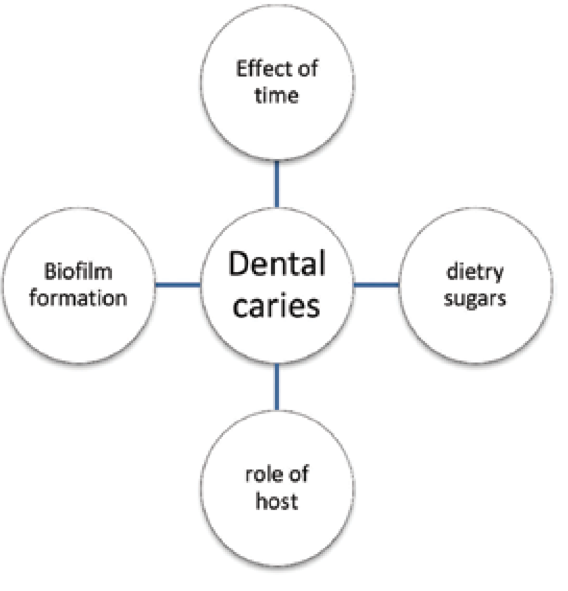

Figure 1. Common factors causing dental caries.

2.1. Dental plaque and biofilm

Biofilms are usually associated with the etiopathogenesis of periodontal diseases [10]. In order to survive in a niche, the ability of microbes to adhere to tooth surface and multiply in protected environments like tooth cervices and periodontal pockets is very important. This accumulation of microbes on the tooth surface is called *plaque*, which can be defined as "a structure entity in which the microbes are embedded in a highly organized intercellular matrix," These microbes are involved in different metabolic, physical, and molecular interactions. This consortium provides advantages to the participating microbes for resistance to antimicrobial agents, increased pathogenicity, growth, and host defenses [11]. Four stages involved in the biofilm formation are summarized in **Figure 2**.

The primary colonizers of tooth form the biofilm by auto-aggregation and co-aggregation resulting in different morphological structures. The microenvironment moves from aerobic to facultative anaerobic [10]. The bacteria multiply and in matured biofilm occur. Quorum sensing is another important characteristic seen in biofilm-associated bacteria, which actually involves the regulation of specific gene expression. This occurs by means of accumulation of different signaling compounds that facilitate the intercellular communication. This gives biofilm their unique characteristics [12].

2.2. Microbiology of dental caries

The interaction between bacteria and its surrounding epithelium is acute element in bacterial infections. If left untreated pain, infection, and tooth loss depending on the severity will occur. Dental plaque is a sticky substance that sticks to the surface of the teeth. It is considered as complex biofilm that is also the main cause of dental caries [13]. Dextran, produced

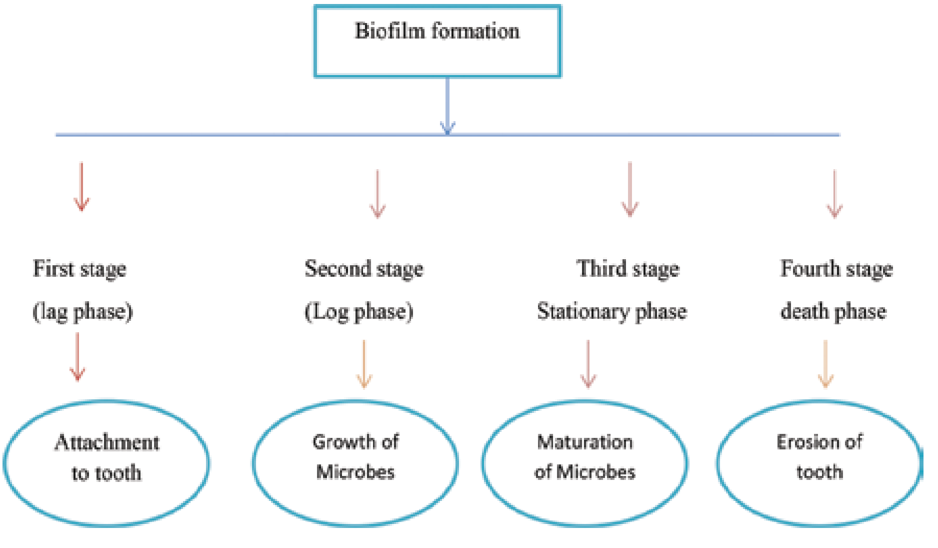

Figure 2. Stages of biofilm formation.

by the dietary sucrose fermentation by *Streptococcus mutans*, is responsible for the stickiness of plaque. As a result of fermentation, *S. mutans* produce lactic acid, which ultimately starts enamel decalcification. This plays a role in initiation of enamel caries. In fact, the development of dental plaque depends on the result of interaction between the plaque adhesion to the tooth surface and the physical shear forces involved in dislodging and removal of plaque [14]. If the dental plaque is not removed properly, tooth decay will flourish [15]. The mature dental plaque is embedded in a matrix of bacteria and host polymer that includes proteins, DNA secreted by cells, and polysaccharides [16–19]. This provides the protection of bacteria against host defenses and predators, from desiccation and enhanced resistance against antimicrobial compounds [20]. *Streptococcus mutans*, *S. mitis*, *S. constellatus*, *S. sanguis*, *S. salivarius*, *S. anginosus*, *S. gordonii*, *S. intermedius*, and *S. oralis* are some of the primary acid-tolerant bacteria that are associated with dental plaque [21]. Accumulation of plaque in gingival and subgingival regions shifts the microflora from gram positive to gram negative. This can cause the periodontal diseases [22]. Dental caries is linked with high blood pressure, diabetes, heart diseases, and sometimes multiple sclerosis along with continuous pain that gets aggravated by cold, heat, sugar, and drinks [23, 24].

Four main factors are associated with dental caries etiology. These factors are bacteria, time, susceptible tooth surface, and fermentable carbohydrates [25, 26]. Along with these factors, there are certain behavioral and sociodemographic factors that are likely to increase the risk of caries. These include poor oral hygiene, age, improper tooth brushing habits, plaque, and sugar-containing drinks [27].

The oral cavity of human is considered as a complex ecosystem which has both acid-producing and acid-tolerant bacteria. Almost 700 different bacterial species have been known for human oral cavity [28–30], and nearly 200–300 species have been identified for dental plaque [31] using different culture-dependent and culture-independent techniques. *S. mutans* is considered as the main organism responsible for human dental caries. Certain factors like ability to form biofilms, tolerance of frequent and rapid environmental fluctuations, and metabolizing carbohydrates are considered to be responsible for the virulence of these bacteria [32, 33]. In addition, the *mutans* is also associated with bacterial endocarditis, inflammation of heart valves. Synthesis of the extracellular polysaccharides by *S. mutans* from sucrose through glucosyltransferases (GTFs) is considered another important virulence factor that causes caries in humans [34]. This not only facilitates the adhesion and accumulation of the organism on the tooth surface but also provides protection against host immune defenses along with provision of increased resistance against antibiotics and gene expression [35]. This combination of virulence properties allow the *mutans* to colonize the surface of tooth and modify the nonpathogenic to highly cariogenic dental biofilm that ultimately leads to caries formation [36].

3. From synthetic to herbal products

The second primary cause of death in the world is infectious diseases. Treatment of these diseases is problematic today because of severe side effects of different antimicrobials and the growing resistance against all the lifesaving drugs due to their continuous use [37, 38]. The issue becomes much worst with almost 70% of bacteria that cause common infections in hospitals develop resistance to at least one of the common antibiotic that is used for treatment [39, 40]. Even the antibacterial agents can enhance the development of resistant bacterial strains [41]. Different antibiotics like erythromycin and penicillin are effective against dental caries in humans and animals, but because of their adverse effects, they are not recommended in clinical application [42]. Chlorohexidine, penicillin, cephalothin, ampicillin, methicillin, and digluconate are some of the other antibiotics that have effect on dental caries [22]. Recently, resistance has also been observed in cariogenic bacteria against these antibiotics. The development of resistant strains and the associated side effects of these medicines have resulted in diversion of research toward screening of natural products (plants) for anticaries activity as some plants have shown potential against dental caries-causing pathogens [43, 44].

3.1. Herbal medicines from plants

The use of natural remedies from medicinal plants could be an alternative for the side effects of antibiotics like supra-infections, hypersensitivity, and teeth staining. Due to this the search for new antibiotics continues persistently. In fact the failure of different chemotherapeutics and increasing resistant against antibiotics also led to screening of different medicinal plants and their potential use against these microbial pathogens [45]. The significant contribution of medicinal plants to the drug industry, all over the world, was due to the increasing number of phytochemical and biological studies. Medicinal plants are important sources of developing new therapeutic agents. Almost 100 new plant-based medicines were introduced in the United States during 1950–1970. These include vinblastine, deserpidine, etc. From 1991 to 1995, 2% of drugs were introduced in the world including irinotecan, paclitaxel, topotecan, and many

Plant name	Part of plant	Application	Reference
Asteracantha longifolia		Diabetic patients	[50]
Mangifera indica	Leaves	Antidiabetic activity	[51]
Citrus lemon L.	Peel	Antibacterial	[52]
Soymida febrifuga, *Tinospora cordifolia* (Willd.)	Whole plant	Antioxidant, anti-inflammatory	[53]
Terminalia chebula, *Ocimum sanctum*	Whole plant	Urinary tract infections	[54]
Syzygium cumini	Leaves	Dental caries	[55]
Diospyros blancoi, *Phoenix dactylifera*, and *Morus nigra*	Leaves	Antibacterial, caries	[56]
Capsicum annuum	Fruit	Antibacterial, antimicrobial	[57, 58]
Psidium guajava L	Leaves	Antimicrobial, antioxidant	[59, 60]
Aloe vera L	Leaves/gel	Antimicrobial, skin infections	[61–63]
Azadirachta indica	Whole plant, leaves	Antimicrobial, antioxidant	[64, 65]

Table 1. Medicinal plants used in traditional medicines.

others [46]. Drugs derived from plants are used to treat cancer, tuberculosis, different skin diseases, diabetes, hypertension, and many more [47]. The National Cancer Institute collected around 35,000 plants from 20 different countries and evaluated almost 114,000 extracts for potential anticancer activity [48]. Among the approved anticancer drugs worldwide, between 1983 and 1994, 60% are of natural origin [49]. Some medicinal plants that are used to treat different diseases are given in **Table 1**.

Today, oral care products combined with medicinal plant extracts are gaining high interest due to their low toxicity [66, 67]. Cetylpyridinium chloride, amine fluorides, triclosan, and chlorhexidine are not only toxic, but they cause staining of teeth.

4. Secondary metabolites of plants

Different secondary metabolites produced by plants like terpenoids, flavonoids, alkaloids, and tannins are new sources of antimicrobial substances which help in combating resistant pathogens. Plants synthesize different useful substances, majority of which are secondary metabolites and almost 12,000 of them have been isolated [68]. Owing to their diverse structures, synthesizable analogues [69] and frequent usage [70] natural products have become an important source of medicine. Plants have evolved multiple defense systems for their survival because of plethora of rivals in order to fight the environmental stresses [71]. Plants are in fact the complex storehouse of undiscovered bioactive compounds with great potential to be used in medicines [72].

Basically the chemicals produced by plants are divided into two categories, the primary and the secondary metabolites [73]. The *primary metabolites* are involved in the synthesis of the basic building blocks of the plant, while the *secondary metabolites* are involved in the defense mechanism of the plant against different microbial infections [74]. The important secondary metabolites in medicine include flavonoids, alkaloids, terpenes, tannins, and phenolic compounds [75–78]. Unlimited opportunities for drug discovery have been provided by plant extracts, whether pure compounds or standardized extracts, because of their chemical diversity [79]. All the plants that are used in traditional medicine contain diverse substances that can be used to treat different infectious and chronic diseases [80, 81].

The significant contribution of medicinal plants to the drug industry is due to the increasing number of phytochemical and biological studies. In developing countries the herbal medicines are important sources of products in order to treat different infectious diseases and also to overcome the problems related with the available antimicrobial agents. Herbal remedies are getting popularity as they provide safe alternatives for treating various types of cancers [82–85]. These remedies are gaining interest because of their multidimensional health benefits like they are even used in different alternative treatments like acupuncture and massage therapy and by various traditional practitioners. The medicinal uses of the plants range from administration of leaves, stem, barks, seeds, and roots to using of the decoction from different plants [86]. There has been an increase in the demand of different herbal products in the last few decades and even in countries like United States, herbal remedies are in use in the form of different dietary supplements [84, 87, 88].

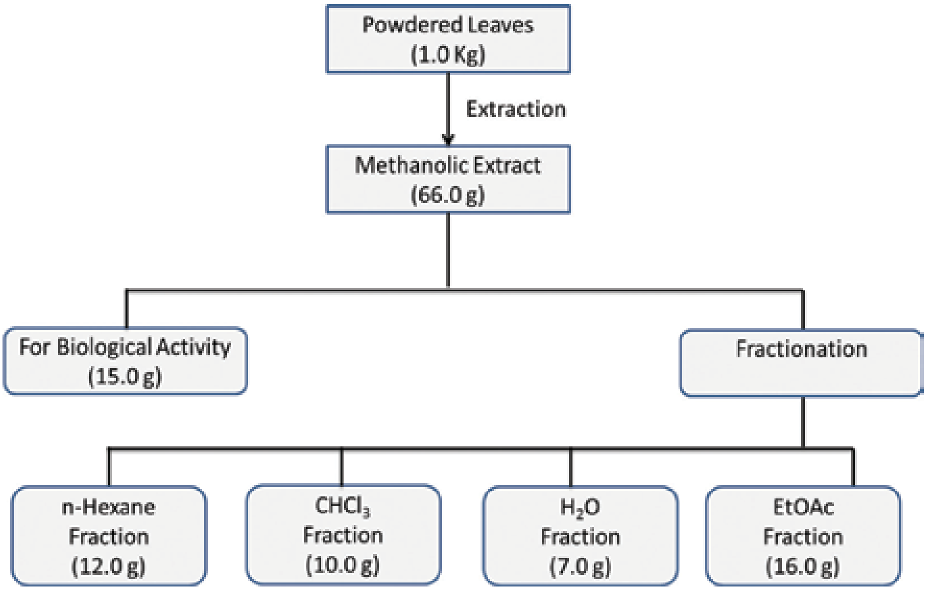

Figure 3. Extraction and fractionation from the leaves of *Syzigium cumunii*.

Figure 3 represents the general layout of extraction of useful secondary metabolites from plants taking *Syzygium cumini* as an example using different solvents.

5. Why to go for natural resources

The commercially available chemicals, if not all, to most of the antibiotics commonly available to treat oral infections, can alter the oral microbiota along with certain undesirable side effects [41, 89] and bacterial resistance [90]. An alteration in the microenvironment like wounds, malnutrition, abrasions, and different pathological conditions enhances disease development [91]. Also, the presence of ethanol that is commonly found in mouth washes has been linked to oral cancer [66, 67, 92, 93]. As a result of this, the indiscreet use of allopathic drugs and improper diagnosis of microbial infections not only lead to untargeted therapy, but it also gives way to resistant pathogens [94, 95]. Therefore, the search for alternative methods and products continues, and for that the phytochemicals isolated from plants that are used in traditional medicines are proving to be the good alternative to synthetic chemicals [96].

In developing countries the herbal medicines are proving to be an important source of products in order to treat different infectious diseases and also to overcome the problems related with the available antimicrobial agents. Herbal remedies are also getting popularity for treating various types of cancers as they provide safe alternative [82–85].

6. Conclusion

Prevention of dental caries is challenging, as the incidence of the disease is very high in general population and it occurs in economically deprived people who cannot afford the commercially available oral hygiene products [97]. Even though caries is known to be an infectious disease for decades, very little effort has been done to use this information clinically [98]. Different from other commercially available chemicals, they not only alter the oral microbial environment but also play a role in developing the resistant strain. Hence, in order to prevent dental caries, it is time to focus our attention toward natural resources which have vast abilities to inhibit the growth of microbes that are responsible for caries. For this, we need to isolate the bioactive compounds from plants with little or no harmful effects.

Author details

Lubna Tahir* and Rabia Nazir

*Address all correspondence to: lubnatahir@yahoo.com

Applied Chemistry Research Centre, Pakistan Council of Scientific and Industrial Research Laboratories Complex, Lahore, Pakistan

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Chapter 4

Etiology of Secondary Caries in Prosthodontic Treatments

Arzu Zeynep Yildirim Bicer and Senem Unver

Additional information is available at the end of the chapter

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Abstract

When preparing prosthetic restorations, dentists always try to create restorations functionally ideal while not compromising on esthetics. The factors that make a restoration successful include how well they fit both internally and marginally, their ability to withstand punishment without breaking, and their visual appeal. Imperfect marginal adaptation can lead to unpleasant and unwanted side effects such as plaque accumulation, marginal discoloration, microleakage, carious and endodontic lesions, and periodontal disease. If there is a gap between the crown and the prepared tooth, this can result in the dissolution of the luting material. If the fit of the restoration and the thickness of the cement are designed to be favorable, the cement is not dissolved and the abutment tooth is prevented from secondary caries. The marginal fit of the restorations is considerably affected by the materials and techniques used when making dental crowns. This chapter contains reviews on marginal fitting and caries.

Keywords: caries, marginal fitting, restoration

1. Introduction

Throughout the history of dentistry, dental clinicians, prosthodontists, and manufacturers have strived to create dental restorations that are both esthetically pleasing and function perfectly. Multiple factors determine how therapeutic the restorations are and how long they last. Just how successful a dental restoration depends on three principal factors: how esthetically pleasing it is, how resistant it is to fracturing, and marginal adaptation, meaning how well they fit [1, 2]. More recently developed materials have a high esthetic value and are mechanically very resilient. The factors that affect marginal adaption include how well the restoration bonds to the prepared surface, how effective the seal is, and the characteristics of the adhesive used to bond the restoration to the tooth. When a prosthetic restoration does not fit properly, this can cause plaque accumulation [2, 3]. This in turn can lead to microleakage and endodontic inflammation [4], and it increases the probability of carious lesions [5, 6]. The periodontal and endodontic lesions that form as a result may require the prosthetic restoration to be replaced or necessitate endodontic treatment, or even tooth extraction.

2. Caries

"Dental caries is determined by the dynamic balance between the pathological factors that lead to demineralization and the protective factors that lead to remineralization." [7] Caries is a tissue consisting of densely packed crystallites formed in a single axis having both inter- and intra-prismatic micropores measuring between 1 and 30 nm in width. Caries appears in the enamel first and this is accompanied by hypermineralization of the dentine below the cavity [8]. One common characteristic of this is sclerotic dentinal tubules [9]. The dentine starts to demineralize at the outer edge of the lesion matching the outer edge of the enamel lesion [10]. Dentinal caries develops and spreads quickly from the dentine-enamel border moving under the enamel, and this results in caries [8].

2.1. Secondary caries

Secondary caries develops at the site where the tooth and the prosthetic restoration interface. They are considered the main reason why prosthetics fail no matter what restorative material is used [11, 12].

If the conditions around the seal become acidic, the site will start to demineralize in a manner similar to primary caries because of the process of demineralization and remineralization [11]. All the factors that accelerate the accumulation of biofilm mass or impede its removal can be regarded as potential causes of secondary caries, and this is likely why secondary caries mainly occur on the adjacent surfaces [13] (**Figure 1**).

2.2. Diagnosis of secondary caries

Secondary caries has to be caught early on in order to increase the treatment's chances of success and to stop the hard tissue from being destructed [14–16]. To diagnose secondary caries adjacent to restorations, several different radiographic techniques can be used and these include periapical, bitewing, occlusal, and panoramic imaging (**Figure 2**). In order to prevent wrong diagnoses, radiographic examination must be made together with a clinical examination [17]. It is hard to diagnose secondary carries at the buccal or lingual area on the tooth because these methods only give 2D images. There is a 3D imagine method used by clinicians to assess the area being examined without the need to place other objects in the axial,

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Figure 1. Image of a crown.

Figure 2. Radiographic image of secondary caries around a prosthetic restoration.

coronal, or sagittal planes. This method is called Cone Beam Computed Tomography (CBCT). It is better than a medical CT because it gives 3D tomographic images while subjecting the patient to less radiation. While it is useful in cases where 2D imaging techniques are inadequate, it nevertheless uses more radiation than 2D radiographic imaging techniques, so the technician has to exercise care when using this method [18].

The condition can only be diagnosed as secondary caries if the mineralized tissues around the strain have become soft or if cavitation occurs at the edge of the restoration. The gap will probably contain bacteria, but that does not always mean that secondary caries is going to occur. It is useful to remember that many types of bacteria exist in the mouth and that only some of them can produce caries and only then under certain conditions. In fact, there is no documented proof of any relationship between the onset of secondary caries lesions and gaps where the prosthetic restoration joins the tooth, other than when the gaps are large, for example, 250 [19] or 400 μm [20].

3. Etiology of secondary caries

3.1. Microleakage

The classic definition of microleakage is the movement of matter, such as bacteria, oral fluids, even ions, into a fluid-filled gap or a naturally occurring structural defect, or between restorations and the tooth [21]. Microleakage is regarded as one of the principal causes of failure in crowns, so it is one of the main factors that determine the clinical lifespan of dental restorations [22]. Not only does microleakage adversely affect a restoration's clinical use, it can also lead to hypersensitivity, discoloration along the margin [23] (**Figure 3**), secondary caries, inflammation, or necrosis of the vital pulp and often requires endodontic treatment [24, 25].

The degree of microleakage depends on several factors including the tooth's own structure, the luting or bonding agents used to cement the restoration, and the interaction of other factors involved with dental restoration [26].

3.2. Marginal and internal fitting

One of the main factors affecting the longevity of dental restoration is marginal adaptation or how well it fits the tooth [27]. Any gap in the seal exposes the cement to the oral environment. With large gaps, the luting agent is more exposed to oral fluids, and this accelerates both the breakdown of the cement and microleakage [28]. These imperfections along the edge make it easier for oral bacteria to stick and for food and other refuse to build up ultimately leading to plaque retention. This alters the way the subgingival flora is distributed, which in turn leads to the onset of periodontal disease [29] and secondary caries [30].

Fit is determined by many factors such as fabrication [31], the type of CAM system used [32, 33], the number of units in the substructure [34], the tooth's location and preparation [35], the rigidity of the material [36], the type and thickness of the luting agent [37], and the presence of a luting agent [38]. Both the size of the gap at the edge and the amount of resin used have to be kept to a minimum in order to provide a better fit and to increase the cement's longevity [39].

Figure 3. Discoloration along the edge of an endocrown restoration.

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Maintaining the gap along the edge as small as possible is very important because the potential for microleakage increases as the size of the gap increases [40]. No matter what type of cement is used, gaps between 100 and 120 μm are considered clinically acceptable [41] in terms of minimizing the problems that might result in cement loss [42]; 90 μm or less is the acceptable size for gaps in computer-aided design/computer-aided manufacturing (CAD/CAM)-generated restorations [27, 43–45]. Variations in the internal fit can cause fatigue, possibly weakening the restoration. The thickness of the layer of dental cement along the axial walls of the preparation affects how well the restoration sits in place. Among the factors that influence film thickness are preparation, how the margin is designed and configured, how rough the surface is, how much pressure is applied during cementation and for how long, the cement's powder/liquid ratio, the type of cement, the spacers used, and the method used for cementation [46].

The fitting of the restoration and proximal surfaces may be checked before cementation to prevent any overhangs that can cause plaque accumulation and secondary caries. Even tiny overhangs, which are often hard to detect clinically, can lead to plaque accumulation, periodontal disease, and the onset of secondary caries. The edges of crown's margins are susceptible to microleakage, and clinical tests have shown that large gaps can result in secondary caries [47, 48]. Caries is the second most common biological complaint in crowned teeth next to the loss of pulp vitality [49].

Laser videography [50], profile projection [51], micro-CT, and CAD/CAM scans [52] are some of the ways in which the adaptation of prosthetic restorations can be assessed. One commonly used technique is the cement analog or Replica Technique (RT). This method allows the dimensions of the internal and marginal gaps in prosthetic restorations to be estimated with a fair degree of accuracy [53]. This nondestructive technique involves sitting the restoration on top of a prepared die using an impression material instead of cement. Once set, the impression material and the restoration are carefully removed from the die and the thickness of the cement analog layer is measured [54–58]. Another nondestructive method that can be used to check the size and shape of gaps in prosthetic restorations is the "Weight Technique" (WT). It costs less than RT and is easier to do. In WT, the material used to simulate the cement layer is weighed at certain points rather than having its thickness measured like in RT. The weight corresponds to the thickness of the gap between the restoration and the die [59].

The gap between the tooth and the edge of the restoration, known as the marginal gap, is measured to determine how well the restoration fits the tooth and is called absolute margin discrepancy [60, 61]. Marginal gap has been given several definitions: vertical marginal discrepancy, horizontal marginal discrepancy, over-extended margin, under-extended margin, seating discrepancy, and absolute marginal discrepancy. Of them all, absolute marginal discrepancy is regarded as the best method for measuring the marginal gap because it yields the largest error [62]. Currently, there is no standard method for measuring how well the margin fits but the most popular method is to use a microscope to measure the distance once the embedded specimens have been sectioned. This method cannot be used "in vivo" [63].

The gap between the inside surface of the crown and the outside surface of the tooth can be checked using a silicone paste in order to evaluate discrepancies. This technique is not without its faults, and readings can be adversely affected by defects in the silicone material in the area being measured and by inaccuracies when reading the measurement of the thickness of the paste under a microscope [64].

3.3. Material type

Different materials such as metal or ceramic are used to make the framework for the prosthetic restorations. The "gold-standard" metal-supported restorations have superior mechanical properties and proven longevity in clinical trials and are the restoration of choice today [65]. While metal-ceramic hybrid crowns are very strong, the increase in the popularity of esthetically attractive restorations in recent years has promoted the development of crowns that are entirely ceramic [37]. Zirconia has started to become popular as a framework material in all ceramic restorations because of such characteristics as high biocompatibility, superior mechanical properties, corrosion resistance, low affinity for plaque accumulation, no allergic reaction to metal in the gingiva, as well as its poor ability to conduct heat and electricity [66]. Zirconia also has some downsides such as phase transformation in reaction to surface treatments, being opaque, and degrading at low temperatures [67]. The most common complication observed in zirconia substructure restorations is reportedly the superstructure ceramic layer coming away from the substructure in layers or by fracturing [68, 69].

All ceramic crowns are esthetically very pleasing and work just as well with anterior teeth as with posterior ones. They interact well with the gingival tissues and offer a great biocompatibility [70]. On the downside, however, they can be brittle (particularly those made from glass or feldspathic ceramics). They fracture easily and can cause excessive wear on the opposite teeth. They also necessitate a greater tooth reduction and tend to favor certain techniques over others [71].

Contrary to direct composite restorations, CEREC composite blocks are produced under the best conditions possible, thus improving the degree of monomer polymerization and preventing voids from being formed, thereby giving them optimal mechanical properties [72].

Semi-sintered zirconia requires shorter milling times and produces less wear on the cutting burs. However, this technique requires a final sintering stage after milling [73]. This sintering procedure entails a certain amount of shrinkage. This technique does have its downsides such as uncertainty with respect to the correct enlarging factor and a marginal fit that does not meet the most exacting demands. On the contrary, milled, fully sintered zirconia is subjected to hot isostatic pressing and offers a much better marginal fit [63].

The strength and fit of the final restoration are affected by such factors as the different materials and techniques used when manufacturing it [74]. Clinicians are advised to adhere closely to the technical guidelines in order to overcome the problems inherent with marginal gaps. It is recommended that they use only the highest-quality materials when constructing prostheses so as to achieve the best marginal compatibility [75, 76].

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3.4. Fabrication method

Prosthetic restorations can be made in a number of ways depending on the material used for their cores [77].

Metal-ceramic crowns are still the most common way to make full coverage crowns and fixed partial dentures [78]. Many studies have been done into the fit and distortion of metal-ceramic crowns, including how the manufacturing process affects fit. Since the ceramic veneer and the alloy coping expand at different rates under heat, firing the ceramic might affect how the crown fits. The casting process is a complex one. This plus the different rates at which the various materials expand and contract make it very difficult indeed to ensure that a casted coping will fit.

The classic method for making the metal core is the "lost-wax technique." However, this technique has several disadvantages such as possible distortion of the wax patterns, imperfections in the cast metal, complicated procedures, and it takes up much time. These disadvantages have been countered now by CAD/CAM and processes such as milling and Direct Metal Laser Sintering (DMLS), which are used now in fabricating the metal frameworks for metal-ceramic crowns. In the CAD/CAM milling system, CAD is used to design a pre-production digital frame, which is then manufactured (CAM) using this CAD data [79, 80]. A solid Co-Cr blank is milled into shape using the digitally created frame as a template. DMLS is a fabrication technology that uses metal powder as an additive. By means of a high-temperature laser beam, metal powder is smelted and forged into the shape of the digital CAD template to make the framework. A thin layer of the beamed area becomes fused, and the metal framework is manufactured by building up layer upon layer of metal in order to achieve the final shape [81]. CAD/CAM and DMLS make laboratory procedures easier and save time [82].

In contrast to metal-ceramic crowns, a high-strength ceramic framework is used that is resistant to loads when constructing ceramic crowns. In addition to being fracture resistant, ceramic crowns owe their success and quality to their esthetic value and near perfect marginal and internal fit [83, 84]. The use of the ceramic systems has increased as new technologies are developed [77].

Various different high-strength materials and manufacturing methods are used in making the framework for ceramic crowns [85–88]. Techniques such as slip casting [89], heat pressing [90], copy milling [85], CAM [86], and CAD-CAM [87, 88, 91] are widely used in the production of copings.

The use of full-ceramic materials in dentistry has developed in parallel with the introduction and use of CAD/CAM systems. Crowns, inlays, onlays, laminate veneers, and abutment are among the many dental restorative methods that make use of CAD/CAM systems [92, 93]. Resin composites or porcelain shaped using CAD/CAM technology give patients esthetically pleasing restorations that are of similar appearance to teeth and that can be cemented into the patient's mouth during the same appointment. This decreases the treatment time and makes interim prostheses unnecessary (**Figures 4** and **5**). With the CAD/CAM milling of porcelain blocks and optimum manufacturing conditions, the restorations that have a higher intrinsic strength in the laboratory can be fabricated [94, 95].

Figure 4. CAD imaging.

Figure 5. All-ceramic restoration.

In CAD/CAM systems, extra space for the cement can be programmed, potentially making for a better fit both marginally and internally [63]. When casting a prosthetic restoration die, spacers have to be added to form the space for the cement but this space can be created and minutely adjusted digitally using CAD/CAM. The accuracy of fit was found to depend much on the spacing of dies [96].

There are some factors that can influence the marginal fit when using CAD/CAM system such as the scanning, the design software, sintering, and milling processes themselves, any and all of which can lead to errors when manufacturing the ceramic framework. One reason for the difference in marginal gaps seen between copings made using CAD/CAM technology and those made using only CAM technology might be the long fabrication chain involved in the CAM process, which is as follows: (1) preparing the master cast and spacers, (2) adding the wax, and then (3) removing the wax pattern from the master cast. Manually adding the wax can result in nonuniform layers, and this in turn can create a distorted product during the sintering process. Taking the cast off can also adversely affect accuracy. Furthermore, it is harder for a scanner to scan the concave inner surface of the wax pattern than the convex master cast [63].

There have been many studies evaluating marginal and internal fitting of fixed prosthetic restorations prepared with different production techniques from different materials [82, 97, 98]. No significant difference between the various manufacturing techniques was reported. While the thickness of occlusal cement was highest with the laser-sintering method, used for making the metal framework, this thickness is approved as acceptable values [82].

Even with all the advances in manufacturing technology, it is still a major challenge to create a long-lasting and well-sealed marginal fit where the tooth meets the crown [99]. As a result, CAD/CAM systems may be more advantageous because ceramic materials with a high mechanical resistance can produce more esthetic restorations in a shorter time.

3.5. Cementation

Marginal gaps that are an important component in fixed prosthetic restorations need to be sealed effectively with luting cements, and cements preserve the tooth from microbial invasion [100]. Microleakage and marginal openings are important causes of fixed restoration failures. The increase of the marginal gap in the fixed restorations results in greater microleakage and cement disintegration with cement exposed to oral fluids [37]. Because of the cement decomposition or dissolution in oral fluids, shrinkage on setting, the cement losses the bonding effect between the cement and the dentine or cement and restoration [101]. When the cement does not seal the gap properly, this can lead to inflammation in the pulp and subsequent pulpal necrosis, which in turn adversely affects longevity of the restorations [100, 102]. Other factors contributing to microleakage include the mechanical properties of the cement and the degree to which the cement adheres to the tooth. One final factor contributing to the severity of microleakage is the adhesive having weak-bonding properties [103].

Another cause of failure of nonmetallic esthetic restorations is clinical fractures [104]. It has been shown that resin-luting agents have the strength necessary for all-ceramic esthetic restorations when used together with established bonding procedures, resulting in a very strong luting unit with good retention properties and that is almost insoluble. Generally, resin cements are capable of dual polymerization and are known for being mechanically strong and having excellent esthetic properties [105, 106].

The past 20 years have seen ceramics and composites being used more and more in posterior teeth as well, thanks to the important improvements made in their mechanical properties in addition to advances in cements and their properties [21]. With the development of dentine-bonding agents and the improvements seen in the properties of resin composites for direct filling, resin-based cements have become popular with clinicians working with all-ceramic restorations [37, 106, 107]. The mechanical- and/or chemical-bonding properties of resin-luting agents between the tooth and the restoration are what contribute to the success of indirect, fixed restorations with resin bonding [108]. Resin-based cements possess many ideal properties such as insolubility, very good strength, better adhesion, and the ability to form a solid bond with the tooth [109].

Other factors affect how effectively the adhesive bonds are related to the actual material and they include filler content, monomer composition, and curing mode. The nature of the substrate surface, for example, enamel, alloys, ceramics, dentin, or composites, can also affect the strength of the bond [110]. Significant differences have been noted between adhesive-luting agents in studies investigating at their ability to prevent leakage between the surfaces in cemented restorations [21, 111, 112].

Typically, there are three steps in the process of adhesive cementation: etching, priming, and applying the cement. Every step of this process is technique-sensitive and requires attention to detail [100, 113, 114]. The latest generation of proprietary self-adhesive resin cements is self-etching and bonds to dentine without the need for additional primers or etching agents. Resin cements are self-adhesive and dual-polymerizing. By design, they are easy to use and have good mechanical properties, high esthetic values, and adhere well to both the restoration and the tooth [115]. Even so, the durability of the bond, the resin cement to the tooth and the resin cement to the ceramic surface, is still a crucial point [116–118].

Crowns that are cemented using self-etching resin cements demonstrated much lower average microleakage scores than using self-adhesive resin cement. This might be due to differences in the different cements' adhesion mechanisms. Self-etching resin cement comes with an etch-prime agent with a 2.4 pH and monomers possessing low-molecular weight. They diffuse selectively into the dentine [119] and create a hybrid complex [120, 121]. As a result, these monomers create a small amount of dentine demineralization that allows the cement and the dentine to bond. However, this is not the case with self-adhesive resin cements. They contain multifunctional phosphonic acid methacrylates, and these react with hydroxylapatite [122]. One recent study showed that self-adhesive resin cement presented no evidence of decalcification/infiltration into dentine even though the initial pH value was acidic [123].

Resin-based materials have a tendency to accumulate more plaque, and this plaque is more cariogenic than that found on enamel and other materials used for restoration. Even so, one study has shown that cariogenic bacteria on enamel, glass ionomers, and resin-based materials are the same [124].

Glass-ionomer cement has properties that make it ideal for cementation such as a reduced film thickness and a very low coefficient of thermal expansion coupled to its strong physicochemical bond to both dentin and enamel, as well as its hydrophilic qualities and low solubility. Moreover, glass-ionomer cements leach calcium fluoride giving it the advantage of inhibiting caries [125]. The molecular interactions, ionic and polar, between the cement and the tooth affect the adhesive quality of glass-ionomer cement. These mechanisms are only effective if a close intermolecular contact is achieved between the cement and the tooth. One reason why glass-ionomer cements fail may be the porosities that can appear when the cement is mixing, and these porosities reduce the intermolecular contact between the tooth and the cement [74].

Rosentritt et al. [126] concluded that the resin cements and self-adhesive materials demonstrate good marginal integrity with minimal microleakage. They noted that the easily applied self-adhesive resin cements have the potential to be an alternative to resin cements.

Traditionally, water-based cements have been used to fill the space between the tooth and the restoration. However, the water-based cements are highly soluble in oral fluids, so their ability to seal depends largely on how well the restoration fits [75].

Different cements have different degrees of microleakage [104]. A study of the microleakage results obtained using resin, zinc phosphate, and glass-ionomer cements showed that zinc-phosphate cement is not as successful as glass-ionomer and resin cements in reducing microleakage. One reason for this may be the high solubility of zinc-phosphate cement when compared to glass-ionomer and resin cements in addition to the properties of its bond with dentine, which is entirely mechanical. Clinical studies have shown that despite these negative characteristics, restorations fixed with zinc-phosphate cement are stable for long periods of time. Resin and glass-ionomer cements are less soluble than zinc-phosphate cement and their chemical composition allows them to bond strongly both chemically and mechanically with dentine. In experimental conditions, resin and glass-ionomer cements performed better in terms of microleakage when compared to zinc-phosphate cement. However, only though long-term clinical trials will the advantages and disadvantages of the various cements in terms of durability become clear [127, 128].

Furthermore, maintaining microleakage to a minimum requires the use of cements with good sealing properties. Of all the different types of cements that are used in dentistry, resin-based and glass-ionomer cements have shown the best results due to their leaching of fluoride ions, creating an additional mechanical bond with the tooth [75, 76].

4. Conclusion

Nowadays, with the developing technology, there are many restorative materials and different fabrication methods for prosthetic restorations. Marginal adaptation is the most important factor for clinical use and success of the restorations. Failure to provide marginal adaptation increases microleakage and causes microorganisms to colonize between tooth and restoration, thus causing secondary caries. In fixed prosthetic restorations, CAD/CAM technologies can be used to prepare infrastructures to have optimal marginal and internal fitting, mechanically resistant, biocompatible, and low cement spacing. More bonding efficiency and less water solubility of the adhesive resin cements result in less microleakage than other cements; for this reason, adhesive resin cements can be preferred for a suitable option. In glass-ionomer cement, secondary caries risk is decreased because of the presence of fluoride. Before the planning of prosthetic restorations, abutment teeth, periodontal tissues, prosthetic material, cement, and fabrication method must be chosen carefully.

Author details

Arzu Zeynep Yildirim Bicer* and Senem Unver

*Address all correspondence to: dtzeynep@yahoo.com

Faculty of Dentistry, Depertment of Prosthodontic, Gazi University, Ankara, Turkey

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The Relationship between Orthodontic Treatment and Dental Caries

Gamze Metin-Gürsoy and Fatma Deniz Uzuner

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Abstract

Orthodontic treatment is the main treatment procedure to achieve a well-aligned dental arch and an esthetic smile. For this purpose, various types of removable or fixed orthodontic appliances are designed. However, each has their specific disadvantages. The most important one is that orthodontic appliances especially the brackets and the ligation mode create new retention areas in addition to blocking plaque-removing shear forces arising from fluid flow and masticatory loads with a resultant undesired effect of accumulation of dental plaque. Increased amount of dental plaque containing cariogenic bacteria is the main etiologic factor in decalcification of enamel during orthodontic treatment. This demineralization of the tooth surfaces results in appearance of white spots or even caries. However, in the literature, there are conflicting results in the relationship between orthodontic treatment and development of dental caries. Many preventive methods such as topical fluoride application, using bonding materials releasing fluoride, using mouth rinse with sodium fluoride, applying chlorhexidine, and so on were defined. The general comment of the authors is that supplying an adequate oral hygiene has the main role in prevention of demineralization-caries during orthodontic treatment. In the light of the previous studies' results, it can be concluded that professional application like a varnish can be provided for patients who have high caries incidence.

Keywords: orthodontic treatment, conventional brackets, self-ligating brackets, enamel demineralization, white spot lesion, dental caries, microbial colonization

1. Introduction

Malocclusions are not life-threatening conditions; however, they can affect the health of oral tissues and may cause psychological and social problems [1]. Nonalignment of the teeth on

Figure 1. Extreme enamel demineralization and cavitation.

the jaws may cause dental caries due to the accumulation of dental plaques resulting from difficult-to-reach areas in the mouth. For this reason, dental caries is seen as an important side effect of malocclusions. However, the fact that caries formation is directly related to individual oral hygiene leads to many differences in results. There are studies reporting that there is no significant association between malocclusion and caries formation [2, 3]. On the other hand, other authors are reporting a negative correlation which notes that dental caries is less common in individuals with malocclusions [4].

There are many orthodontic treatment methods based on the existing malocclusion type. However, the common goal of all orthodontic treatment methods is to ensure that the teeth are aligned properly on the jaws, as well as in harmony with each other. A balanced soft tissue appearance and an esthetic smile are virtually the greatest passion of patients and orthodontists. Fixed or removable orthodontic treatment appliances used for this purpose may cause some undesirable side effects, as it may be seen in every treatment process. The most common side effect of orthodontic treatments is that they cause changes in mouth flora due to the formation of non-cleanable surfaces, and therefore they cause areas of decalcification on the enamel and eventually periodontal diseases (**Figure 1**) [5–7].

In this chapter, effects of orthodontic treatments on the development of enamel decalcification/caries were discussed in detail. The effects of bracket materials, designs, and different ligations on the levels of cariogenic bacteria were evaluated, the associated microbiota were discussed in conjunction to previous studies' result. Additionally, the prevention methods such as topical fluoride application, using bonding materials releasing fluoride, using mouth rinse with sodium fluoride, applying chlorhexidine, and so on were evaluated.

2. Relationship between orthodontic appliances and dental caries

In conjunction to the malocclusion characteristics, many types of removable or fixed orthodontic appliances are preferred for orthodontic treatments. However, in addition to their usefulness, they may cause undesired side effects. The use of either fixed or removable orthodontic appliance may affect the quantitative and qualitative distribution of the oral microbiota [5, 8]. After the insertion into the mouth, the salivary proteins will adsorb on the surfaces of orthodontic appliances, which play a considerable role in microbial adhesion. Their irregular surfaces act as a retention area for bacterial biofilm. Additionally, the presence of the orthodontic appliances in

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the oral cavity limits the mechanical self-cleaning process providing by saliva and musculature movement. With the resultant effect of all these factors, pH value of dental biofilm drops in the presence of fermentable carbohydrates and accelerates the accumulation and maturation of cariogenic biofilm. The biofilm especially contains *Streptococcus mutans* (*S. mutans*) which are aciduric and acidogenic microorganisms and considered to be the primary etiologic factors of dental caries [9].

2.1. Removable appliances

When the use of removable orthodontic appliances was assessed in terms of active dental caries or tooth loss due to caries, no difference was reported between children with and without removable orthodontic appliances. Oral hygiene in children with removable orthodontic appliances was found to be as good as the oral hygiene of children without removable orthodontic appliances. In another words, in terms of oral hygiene assessment, no difference was observed between individuals using removable orthodontic appliances and those using no orthodontic appliances [10]. In support, Karkhanechi et al. [11] reported that in patients treated with removable orthodontic appliances (**Figure 2**), as indicated by the lower BANA test results, the amount of anaerobic bacteria in supragingival plaque samples was lower due to the better oral hygiene. No such risk was observed in removable orthodontic appliances. Instead, it was found to be safer, especially in patients with poor oral hygiene control [8].

On the contrary, other authors [12, 13] reported the undesired effects of removable appliances on tooth enamel. Batoni et al. [14] reported a higher amount of *S. mutans* in children using removable appliances. Considering the acrylic removable appliances; there may be plaque accumulation and even calculus on the unpolished acrylic surfaces, especially in noncompliant patients. Acrylic structure of them may influence the proliferation of microorganisms when it acts as a food deposit. Depending on its smoothness and size, it may provide plaque accumulation that leads to enamel decalcification [9, 12, 14]. Addy et al. [15] showed that palatal plaque scores were significantly higher in wearers of removable appliances compared with a control group without orthodontic treatment. As these appliances mainly cover the lingual/palatal surfaces of the teeth, plaque occurrence in that region tend to be higher than other sides.

Figure 2. Acrylic removable appliances.

Lessa et al. [16] reported that *S. mutans* colonies were observed on all acrylic base plate in a week, which showed that the acrylic surfaces of appliances act as a sponge for microbial colonization. It has been noted that microorganisms can penetrate into the acrylic base of removable appliances as deep as 1–2 mm, making disinfection difficult. For this reason, oral hygiene control in patients wearing acrylic orthodontic removable appliances is essential. However, frequency and skill of brushing the teeth is related mainly to patient compliance and awareness. Besides, toothbrushes cannot clean the appliances completely. In addition to brushing, using antimicrobial agents for disinfection has been advised. Both methods need cooperation of the patient [16]. Professional compliance-free methods are preferred to overcome these problems. For this purpose, Farhadin et al. [12] evaluated the effect of silver (Ag^{+1}) nanoparticles added into acrylic baseplates on the amount of *S. mutans* colonization. Ag^{+1} particles have been defined as antimicrobial agents, which destroy bacterial membranes. The authors reported that including Ag^{+1} nanoparticles into the acrylic plate had a strong antimicrobial effect against *S. mutans*. On the other hand, the risk of silver toxicity has to be taken into consideration.

Different form the acrylic removable appliances, the thermoplastic appliances that are being used both for the treatment, correction of the malocclusion, and retention purposes cover all surfaces of the teeth and 1–2 mm of the gingiva (**Figure 3**). They might influence oral microbial flora during the retention period because they avoid the cleaning effect of saliva on tooth and oral mucosa; thus, colonization of *S. mutans* and *Lactobacillus (LB)* on dental surfaces increase [13]. Also, Low et al. [17] reported that thermoplastic appliances had micro abrasions and irregularities that might contribute to bacterial adhesion.

Figure 3. Thermoplastic appliance.

2.2. Fixed appliances

Compared to removable ones, fixed appliances pose a significant risk due to the changes in the normal flora of oral cavity. It is noteworthy that plaque accumulation is greater in individuals treated with fixed orthodontic appliances compared to those treated with removable ones [5, 8, 11].

In fixed orthodontic treatment, orthodontic bands, and brackets, ligatures, and so on placed on the teeth cause an increase in the number of plaque retention areas and also they result in difficulty in ensuring proper oral care. Also, they construct a barrier for the tooth enamel to plaque removing shear forces arising from masticatory loads and fluid flow, so that dental plaque accumulation and formation arises. In conjunction with poor oral hygiene, the number and percentage of oral microorganisms are tended to increase during fixed orthodontic treatment [18, 19].

A significant increase in the amount of *Porphyromonas gingivalis, S. mutans, Streptococcus sobrinus* (*S. sobrinus*), *Lactobacillus casei (L. casei)*, and *Lactobacillus acidophilus (L. acidophilus)* in the saliva are observed with the start of the fixed orthodontic treatment [5, 20]. Among other species, mainly *S. mutans* and *Lactobacillus* bacteria have high concentration in oral flora and higher adhesion capacity on brackets and primarily responsible for dental caries [20, 21]. *S. mutans* uses sugars and produces acids that cause enamel demineralization, which will eventually turn into cavitation. Although *S. mutans* increases in mouth flora especially with the start of fixed orthodontic treatment, at the end of the treatment, there is a decrease because oral hygiene can easily be attained after the debonding of fixed orthodontic appliances. On the other hand, it has to be taken into consideration that the amount of *S. mutans* may increase due to the formation of retention areas by fixed or removable appliances used for retention.

The plaque accumulation and microbial adhesion during orthodontic treatment with fixed appliances depend on different variables [22]. Such as:

1. Bracket design and material (surface roughness of materials, surface free energies),
2. Material of ligation,
3. Proximity of the gingival sulcus to the bracket,
4. Surface area of the labial enamel relative to the bracket,
5. Excess bonding around the bracket,
6. Position of the teeth in the dental arch,
7. Oral hygiene habits, poor decayed, missing, and filled tooth scoring (DMFS), and age.

2.2.1. Bracket design and material (surface roughness of materials, surface free energies)

Surface characteristics such as the surface roughness and surface free energy affect the amount of bacterial adhesion to orthodontic materials. A rough surface provides suitable niches for bacterial colonization, and a material with high free surface energy attracts more bacteria. In bacterial retention, other than surface roughness of materials, surface free energies also play a decisive role. It is stated that the most important factor initiating bacterial accumulation is surface free energies [21, 23–27].

Various bracket types with differentiated morphological characteristics and physical properties showed different influence on the adhesion of dental plaque and that of the microbiota. Given that, the porous structure of the material of the brackets would maintain an ecologic niche for microorganism adherence and biofilm formation [28, 29]. The microorganisms exhibited the highest adherence to the esthetic brackets (**Figure 4a**). In-vitro studies showed that the affinity of the microorganism for metal brackets (**Figure 4b**) was significantly lower than that for brackets made of plastic or porcelain [30].

The level of oral hygiene, diets, fluoridation, potential local differences in the saliva wetting, and the presence of an early salivary pellicle might influence the amount of iatrogenic enamel decalcification and/or white spot lesion (WSL). Considering the local differences in saliva wetting and distribution by intraoral soft tissue dynamics, it may be hypothesized that labial and lingual enamel areas may be differentiated in terms of WSL formation [31]. Wiechmann et al.

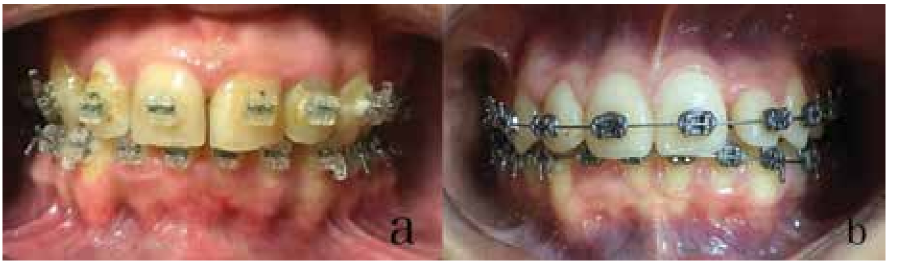

Figure 4. Esthetic brackets (a), metal brackets (b).

[31] evaluated the incidence of WSLs in subjects treated with customized lingual multibracket appliances and reported distinct reduction in WSLs when compared with previous reports of enamel decalcification after conventional labial multibracket treatment [31].

2.2.2. *Material of ligation*

In addition to morphology and design of orthodontic brackets, the bracket ligation type may provide an increased number of retention sites for microbial colonization. The effects of bracket materials, designs, and various ligation modes on the levels of cariogenic microbiota have been evaluated in the literature [1, 22, 23, 25, 32]. However, conflicting results were declared.

Teeth ligated with elastomeric ligatures have been found to attract higher numbers of bacteria than steel wire ligations [32]. The elastomeric ligatures in the oral environment allow for the adsorption of potassium and sodium in the initial phase followed by calcium and potassium precipitations, which stabilize the formed film that accumulates the dental plaque [33]. For this reason, it was suggested that the use of elastic ligatures should be avoided in patients with inadequate oral hygiene [19]. On the contrary, Sukontapatipark et al. [34] reported that the method of ligation did not appear to influence the bacterial quality on tooth. Similarly, Forsberg et al. [32] reported no difference in the periodontal conditions of the treated patients with either elastic or metallic ligatures. These results may be due to the frequent change of the elastomeric ligatures on a monthly basis during the orthodontic treatment. Therefore, the renewal of elastic ligature eliminates the previous bacterial attachment, and each time, a new cycle of colony formation is initiated on new elastic rings.

To eliminate the undesired effect of ligation materials self-ligating (SL) brackets which rely on mobile opening closing mechanism/clips rather than ligatures, to hold the arch wire in place may be preferred [28]. Given that lack of ligature materials, SL brackets were expected to have better values for periodontal status and caries development because of having less retentive sites. In another words, SL brackets might be considered presumably hygienic. On the contrary, the expected beneficial effect of the self-ligating brackets is not confirmed. Even though the SL brackets eliminate the use of ligatures, they often consist of opening and closing mechanisms, which may provide additional plaque retention sites. In addition, there might be plaque and food impactions in the space under the closing mechanism, which could not be brushed by the patient without opening the mechanism. Thus, a theoretical advantage may be eliminated in reality [35].

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In literature, there are few studies with diverse results comparing the SL brackets with elastomeric ligated conventional brackets (CB) [36–38]. Some researchers defined that elastomeric ligated CB causes more plaque accumulation and periodontal inflammation than SL brackets [19, 36, 38]. However, others reported no significant difference [37]. On the contrary, higher bacterial colonization and poorer periodontal health with SL brackets was also reported [39]. When the SL and CB with steel ligatures compared, it was revealed that SL brackets do not have an advantage over CB with steel ligatures with respect to colonization of *S. mutans* and *LB* [40].

2.2.3. Proximity of the gingival sulcus to the bracket

Plaque formation is common in the gingival and lateral regions of the bracket base and behind tie-wings. Following the fixed orthodontic application on the tooth surface, the most plaque build-up is observed on tooth surfaces between the two brackets and behind the arch wire [34].

2.2.4. Surface area of the labial enamel relative to the bracket

Plaque accumulation is seen more in gingival region, and plaque accumulation is least seen in the incisal parts of the teeth [41]. O'Reilly and Featherstone [42] noted that decalcification formed immediately around the brackets and bands, not farther away along the buccal enamel surface.

2.2.5. Excess bonding around the bracket

In fixed orthodontic treatments, excessive composite around the bracket base are the most suitable areas for plaque retention due to their rough surface structure. Surface free energy characteristics play an important role in the initial *S. mutans* adhesion to orthodontic materials. Many different adhesive agents, such as composite, compomer, and resin modified glass ionomer cement, are used in bonding fixed orthodontic attachments to the teeth. It is a known fact that bacteria accumulate more on adhesive agents rather than the brackets on the teeth. The higher the surface free energy, the greater the bacterial retention on the material is. The difference between surface free energies of the adhesive agents is all related to the chemical structures, the hardening mechanisms, and the reactive activities on adhesive surfaces. In this respect, composite, compomer, and resin modified ionomer cement can be listed in accordance with the level of surface free energies from low to high [23, 24, 26, 27].

2.2.6. Position of the teeth in the dental arch

Buccal surfaces of the maxillary molars and the lingual surfaces of the mandibular molars accumulate more plaque than other sites do [43]. At the posterior region, there might be greater food impactions between archwire and soft tissue. In spite of the tendency for more effective and thorough brushing of anterior rather than posterior teeth, maxillary and mandibular lateral incisors were declared to have the highest incidence of white spot lesions (WSLs) [35, 44].

2.2.7. Oral hygiene habits, poor decayed, missing, and filled tooth scoring (DMFS) and age

Especially younger patients seem to have higher DMFS. The colonization of *S. mutans* progressively increases with age [45–49]. The highest amount of *S. mutans* colonization occurs at completion of the deciduous dentition, as the fissures and tight approximal contact areas between deciduous molars provide suitable sites [49]. Previous researches have reported increased caries activity in preadolescents and adolescents compared with young adults [45, 46]. The composition and amount of salivary secretion may vary with age, and thus, the bacterial adherence may differ [47].

In a study [48] in which caries evaluations were made from the mixed dentition stage to the permanent dentition stage, patients were treated with both removable and fixed orthodontic appliances. It was reported that at the end of the treatment, no difference was observed between patients who received an orthodontic treatment and those received no orthodontic treatment in terms of decayed, missing, and filled tooth scoring (DMFS) results. However, it should be noted that patients with a high pre-treatment DMFS score, especially in the first molar teeth and the second premolar teeth, form the high risk group, and these individuals must be included in prophylaxis programs [48].

3. Methods for preventing caries during fixed orthodontic treatment

Iatrogenic decalcification of tooth enamel and the development of visible WSLs are undesirable side effects of orthodontic treatment with fixed appliances. This enamel decalcification undermines the esthetic appearance even though the correction of the malocclusion is achieved (**Figure 5**).

Prevention and treatment of WSLs have become matters of concern among orthodontists. There are many approaches to prevent the accumulation of dental plaque and subsequent enamel demineralization around brackets and bands. Fluoride releasing glass ionomer cement or resin-based composite and fluoridated elastomers have been presented. However, the success in the prevention of demineralization is questionable [50, 51]. Subsequent oral hygiene procedures, such as daily sodium fluoride mouth rinses, may effect protection of enamel demineralization, but the patients' compliances may play important role [52].

Methods to prevent caries in orthodontic patients can be examined under three headings:

1. Struggle against microbial agents; plaque removal and plaque control, use of probiotics, vaccinations.

2. Increasing tooth resistance; fluoride and chlorhexidine applications, casein derivatives, laser applications.

3. Regulation of diet; diet control, restriction of the intake of sucrose-containing foods and beverages, use of non-cariogenic sweeteners, and phosphate supplement.

3.1. Struggle against microbial agents

The best policy to prevent periodontal diseases and caries is daily removing of the dental plaque on the teeth. For this purpose, numerous interventions exist, including mechanical, chemical, and biological methods.

Figure 5. White spot lesions occurred due to fixed orthodontic treatment.

3.1.1. Mechanical methods

Mechanical methods of plaque control involve tooth brushing and interdental cleaning with a wide range of products currently available. Powered toothbrushes are a new high-tech solution to remove dental plaques. Powered toothbrushes with a rotation oscillation action remove plaque more than manual brushes. Other forms of powered brushes produce a less consistent reduction of plaque [53, 54]. The use of a powered toothbrush, especially with an orthodontic brush head, may be of benefit in promoting gingival health and can be recommended for orthodontic patients with fixed appliances. A comparison between the two electric brush heads shows that the orthodontic brush head removes greater plaque than does the regular brush head. Difference of the amount of plaque removed is about 9% between regular brush head and orthodontic brush head, the latter is better in cleaning [55, 56]. Additionally, sonicare brush has been found significantly more effective in reducing supragingival plaque than the manual brush. Improvement in clinical signs, such as reduction in bleeding on probing and pocket depth during orthodontic treatment, is more common in sonicare brushes when used twice daily for 2 min [57]. However, when used three times daily for 2 min, no superiority was observed among ultrasonic, electric, and manual toothbrushes, on microbiologic parameters in orthodontically banded molars [58].

3.1.2. Chemical methods

Commonly used chemical plaque control agents are flour, chlorhexidine, cetylpyridinium chloride, listerine, and triclosan. Chemical methods utilize compounds such as toothpastes and mouth rinses [59]. Fluoride containing toothpastes commonly contain 0.76% sodium monofluorophosphate or 0.22% sodium fluoride. It has been reported that this type of toothpaste reduces tooth decay by 20%. The fluoride concentration of toothpastes should be over 1000 ppm and toothpastes with higher fluoride concentrations are more effective. Daily use of high-fluoride toothpastes can significantly reduce the prevalence and incidence of enamel lesions during the treatment of adolescents with fixed orthodontic appliances [60]. Additionally, daily use of fluoride mouthwashes, which contains 0.05% sodium fluoride, is recommended. Daily rinsing for 1 min with these mouthwashes provides a 50% tooth decay reduction [61]. There is no consensus about the risks associated with using fluoride toothpaste (due to fluorosis) and also about the effect of chronic ingestion of excessive amounts of fluoride in young children [62].

The use of dentifrices with a lower concentration of chlorhexidine (0.50%) was found to be effective for treating gingivitis and bleeding without the risk of tooth staining in orthodontic patients [63].

A 0.2% chlorhexidine gluconate mouth rinse is another type of mouthwashes used to prevent rinse plaque formation and enamel lesions. Compared to fluoride-containing mouthwashes, it is superior in terms of bacterial plaque inhibition and the control of pathogenic organisms. However, chlorhexidine has adverse effects such as tooth and soft tissue staining associated with long-term use [64–66].

The essential oil-containing mouth rinse, Listerine, is effective in reduction of plaque accumulation as well. However, it was mentioned to be less effective than chlorhexidine gluconate [67, 68].

The other chemical compound Triclosan is one of the most commonly used samples of chlorinated diphenyl ether as an antibacterial agent. It has been proved in clinical studies that toothpastes containing triclosan and zinc citrate reduce dental plaque [69].

3.1.3. Biological methods

Biological methods on the other hand consist of probiotics and vaccines, which have recently gained popularity and are being researched extensively. Food and Agriculture Organization and the World Health Organization defined probiotics in 2001 as "live microorganisms which, when administered in adequate amounts, confer health benefits on the host." Probiotics must prevent the proliferation of cariogenic bacterial species, especially *Streptococci* and *Candida* species, on teeth surface. This property of probiotics of neutralizing acidic condition helps in the management of caries [70, 71].

In probiotics-related studies on orthodontics, a reduction in the amount of Streptococcus has been reported; however, no positive effect on white spot lesions has been observed [72, 73].

There is no tooth decay in the areas where the plaque is removed. By effective plaque control achieved by oral hygiene, gingival inflammation is eliminated and remineralization of the enamel surface is ensured. Plaque control requires a little skill and much motivation. The typical order of oral hygiene is defined as flossing, tooth brushing, and mouth rinsing. However, by changing the order of brushing and mouthwash stages, more use of fluoride via toothpaste residues left on the tooth after brushing can be obtained. However, very few numbers of children and adults practice ideal tooth brushing.

Most children spend less than 1 min for tooth brushing and do not brush 38% of the tooth surface, especially those involving lingual surfaces. Adults spend 45–90 s [74, 75]. Thus, using only standardized general prophylactic measures, the development of enamel demineralization during fixed orthodontic treatment is a frequent undesired side effect. Taking this into consideration, improved prophylactic measures, possibly including more stringent in office protocols such as fluoride varnish, are required [76].

3.2. Increasing tooth resistance

Trace amounts of fluoride increase the demineralization resistance of the tooth structure and are of particular importance in tooth decay prevention. The use of fluoride to reduce caries risk was first achieved by fluoridation of drinking water, and then used in diets, toothpastes, mouthwashes, and professional topical applications [77]. However, fluoride is listed in class 4 drug group, which is a highly toxic drug group. A daily dose of 1–3 mg fluoride has been reported as the appropriate dose and reported to be quite safe. Even though 5–10 g of sodium fluoride (2.5–5 g fluoride) intake is fatal for an adult, much less of this amount has toxic effects for children [61].

Topical fluorides (2% sodium fluoride, 8% stannous fluoride, and 1.23% acid fluid phosphate) are used by dentists in the form of solutions or gels. The solutions can be applied directly to the cleaned teeth for 4 min, and the gel forms can be applied directly or by means of plastic, wax, or polystyrene spoons. With these types of applications, tooth decay can be reduced by 40% [78].

It is not clear yet which type of fluoride application is more effective, but it is indicated that fluoride mouthwashes (0.05% sodium fluoride) are more effective [52, 79].

Additionally, fluoride varnishes are among the successful applications in professional anti-caries methods. The first developed products to prevent caries were Duraphat (5% sodium fluoride in a colophony base, Colgate Oral Pharmaceuticals Inc., Canton, MA) and Fluor protector (a clear, transparent polyurethane lacquer containing 0.1% weight fluoride ion as difluorosilane; Ivoclar Vivadent, Inc., Amherst, NY). Fluorinated varnishes are safer, easier to apply, and have more fluoride concentration on the enamel surface compared to other topical fluoride applications [80–82]. They are effective bactericidal and anti-caries agents. Since fluorinated varnishes harden when they come into contact with moisture, the isolation of the applied zone is not necessary. Calcium fluoride builds up on the surface and usually forms fluoroapatite. The high concentration of fluoride on the surface can provide fluoride storage for remineralization [78]. In vitro and in vivo fluoride varnishes studies on orthodontics reported a reduction in the mean areas and depths of enamel lesions adjacent to brackets. Researchers noted that the teeth treated with a single application of a fluoride varnish, exhibited 40–50% less enamel demineralization than the controls [83–85]. Two or three applications per year have been found to be effective [86, 87]. In addition, it has been reported that they cause a decrease in the number of *S. mutans* in plaques and saliva [88]. Even though fluoride varnish is one of the most concentrated fluoride products, they defined to be safer; no acute toxicity has been reported [89, 90].

As another method use of fluoride releasing adhesive can decrease the formation and the severity of enamel demineralization surrounding the orthodontic brackets with independent of patient cooperation as well. Sustained release of a low level of fluoride leads to the formation of a calcium-fluoride layer at the enamel surface. This layer can provide fluoride for remineralization and calcium for neutralization of the acid attack [91, 92]. All the methods used for fluoride application are effective to some degree. The goal of clinicians is to design the most effective combination for each patient, which should be made according to the patient's co-operation status, age, decay history, general health, and oral hygiene.

Similar to fluoride, chlorhexidine is also an agent with an antimicrobial activity. It is available in a varnish form as well as in a mouthwash form. Chlorhexidine varnishes increase remineralization and reduce the occurrence of *S. mutans* [93, 94]. In addition, chlorhexidine-containing varnish is effective in the reduction of gingival inflammation and of plaque accumulation adjacent to the band and brackets [95]. Researchers noted that high-frequency application of chlorhexidine-containing varnish did not result in a greater suppression of *S. mutans* than low frequency application. At the same time, the varnish effect is indiscernible 2 months after application [96].

Various antimicrobial agents are also used to prevent caries. In some rare cases, antibiotics are used, but they are not preferred considering their systemic effects [97, 98].

Casein phosphopeptides amorphous calcium phosphate (CPP-ACP) is a product derived from milk and has anticariogenic activity. During the orthodontic treatment, monthly application of CPP-ACP paste on teeth does not completely prevent WSL development, but it significantly decreases the number of WSL [99]. Using of CPP-ACP with fluoride (MI paste plus, GC America, Alsip, Ill) by a fluoride tray for a minimum of 3–5 min each day at night after brushing prevents the development of new WSL during orthodontic treatment and decreased the number of WSL already present [100]. CPP-ACP is not only available as a paste for home use but also in the form of varnish in combination with fluoride, chewing gum, mouth rinses, lozenges, dentifrices, spray, and energy drinks. The varnish containing CPP–ACP is shown to be more effective than the fluoride varnish to prevent WSL around orthodontic brackets [101–103].

In recent years, the use of argon laser because of its ability to bond brackets in just 5 s has a promising potential in orthodontics. In addition to reducing the chair-time, one of the other beneficial effects is strengthening the enamel to acid attacks. Laser beams resulted in changes in surface morphology, but maintained an intact enamel surface. An in vitro study showed that orthodontic brackets cured with the argon laser could be effective in reducing enamel decalcification and had similar yielded bond strengths with the conventional light-cured brackets [104]. Similarly, an in vivo study showed that argon laser irradiation was effective in reducing enamel decalcification during orthodontic treatment [105].

Nanoparticles (NPs), the insoluble particles smaller than 100 nm in size, are also being used in health. Especially, nanosilver particles, in the form Ag^{+1}, are introduced to be antimicrobial agents given that destroying bacterial membranes through direct contact. Two broad strategies exist to prevent microbial adhesion and/or enamel demineralization during the fixed orthodontic treatment. These are including certain NPs, such as nanofillers, silver, TiO_2, SiO_2, hydroxyapatite, fluorapatite, fluorohydroxyapatite, into orthodontic bonding materials or acrylic resins and coating surfaces of brackets and bands. Information of using nanotechnology is lacking; thus, further investigation to assess possible toxicity related to the NP sizes is required [106–108].

3.3. Regulation of diet

Responsibilities of the dentist or assistant staff to the patient for whom dietary modification is desired are as follows: guidance, providing information, motivation, and encouragement. The patients with braces should be advised about the importance of including foods like fruits, vegetables, grains, and cereals in their diet rather than taking foods such as cakes, pastries, carbonated beverage, and so on, which are high in simple sugars and fats [109–111].

The sucrose taken as part of the diet has two damaging effects on the plaque. First, the frequent intake of sucrose-containing foods provides a stronger *S. mutans* colonization and increases the plaque's potential for caries-formation. Second, the mature plaque frequently exposed to sucrose metabolizes sucrose faster than organic acids, which results in dense and long-lasting low plate pH values. Caries activity is stimulated by the frequency rather than the amount of sucrose taken. The objectives of the diet guide are to identify the sources of sucrose and acidic food in the diet and to reduce the frequency of their consumption. Despite this knowledge, diet change is far from being a very successful method against tooth decay because of the difficulties in providing patient motivation. However, more successful results can be obtained with simple suggestions such as avoiding sugary foods in the form of snacks and avoiding acidic drinks [109, 110]. Additionally, the use of Polyols (the sweeteners that are weakly metabolized (sorbitol) or not metabolized (xylitol) by cariogenic bacteria) is beneficial. Xylitol lozenges can be sucked after a sucrose challenge, which will neutralize the acidity of dental plaque [111].

4. Conclusion

1. Removable appliances are rather safer than the fixed ones in terms of causing iatrogenic enamel decalcification.
2. The design and the material of orthodontic brackets as well as the ligation methods may provide an increased number of retention areas. Thus, facilitating dental plaque accumulation and consequently increased levels of oral microbiota.
3. If there is a good oral hygiene, bracket and ligation type may not cause caries formation. Oral hygiene has the main role in prevention of the iatrogenic demineralization/caries during orthodontic treatment.
4. Patients with a high pre-treatment DMFS score form the high-risk group and, these individuals must be included in professional prophylaxis programs during orthodontic treatment.

Finally, it can be said that although there is an increase in the number of microorganisms in the oral flora following the placement of orthodontic appliances, this cannot play an effective role in the caries formation providing that the oral hygiene is well maintained and the amount of dietary sugar is reduced. Home-care prophylaxis methods should be advised to all orthodontic patients. Additionally, patients' oral hygiene statue and DMFS score have to be evaluated carefully at the beginning of the orthodontic treatment, and professional varnish application can be preferred, if required.

Conflict of interest

There is no conflict of interest to declare.

Author details

Gamze Metin-Gürsoy* and Fatma Deniz Uzuner

*Address all correspondence to: gamgursoy@gmail.com

Department of Orthodontics, Faculty of Dentistry, Gazi University, Ankara, Turkey

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Early Childhood Caries Update

Arzu Pinar Edem

Additional information is available at the end of the chapter

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Abstract

Early childhood caries (ECC) is the most common chronic disease among young children who are less than 71 months of age and is currently represented as a public health problem in various countries worldwide. Dental caries continues to be a major health problem in developing nations because of lack of education, awareness, and poor socioeconomic status. It begins with white-spot lesions on upper primary incisors along the margin of the gingiva and leads to complete destruction of the crown. The potential impact of ECC on the general health and development has been widely reported in the literature. The main risk factors in the development of ECC can be categorized as microbiological, dietary, genetic, behavioral, and environmental. Evidences for effective ECC prevention suggest prenatal and immediate postnatal interventions. Population-based early childhood health systems hold great potential to reduce the burden of ECC. This chapter focuses on diagnosis, prevalence, etiology, preventive strategies, and treatment options of ECC.

Keywords: early childhood caries, etiology, preventive strategies, treatment options, update

1. Introduction

Early childhood caries (ECC) is one of the most prevalent, infectious, biofilm-mediated, and transmissible childhood diseases with long-term progression and caused developmental implications that affect children worldwide especially in developing countries [1]. Those dental decays in infants and toddlers are also known as baby bottle caries, baby bottle tooth decay, nursing bottle caries, nursing caries or rampant caries. Today, the more commonly used terms are ECC and S-ECC in severe cases [2]. ECC describes dental caries affecting children aged 0–71 months. "According to the American Academy of Pediatric Dentistry (AAPD), ECC is defined as the presence of 1 or more decayed (non-cavitated or cavitated lesions), missing (due to caries), or filled tooth surfaces in any primary tooth in a child 71 months old or younger." AAPD confirms that any sign of smooth-surface caries in children younger than 3 years of age is indicative of severe ECC. This definition is detailed as severe ECC constitutes 1 or more cavitated, missing (due to caries), or filled smooth surfaces in primary maxillary anterior teeth from ages 3 to 5, or a decayed, missing, or filled score of ≥4 (age 3), ≥5 (age 4), or ≥ 6 (age 5) surfaces [3]. These lesions involve tooth surfaces that are less prone to caries development.

There are a multitude of risk factors associated with ECC. Feeding habits and a variety of biological, environmental, and socioeconomic factors are involved in the development of ECC [4]. ECC is associated with other general and dental health problems such as ranging from local pain, infections, leading to difficulty in chewing, malnutrition, gastrointestinal disorders, poor child growth or development, and social outcomes [5].

ECC has important etiological bases during the first year of life. Current research suggests that gaps in the knowledge about that disease's progression prohibit effective and early identification of "at-risk" children [6]. Recent studies have focused on the markers of the disease with multifactorial origin. They investigated the risk factors for ECC, such as a variety of microorganisms, the genome along with the oral microbiome (metagenome) and their interactions (transcriptome, proteome, and metabolome) at the tooth surface level genetics, salivary proteins, proinflammatory cytokines and iron deficiency, and so on. They remain largely unknown in caries risk assessment and personalized clinical decision-making.

Understanding the natural history of ECC has an important effect on implementing effective preventive strategies [6]. Prenatal and immediate postnatal interventions are suggested to prevent ECC in evidence-based dentistry. Training on ECC prevention and preventive programs should be started in the prenatal period and should persist in early childhood. Population-based early childhood health systems hold great potential to reduce the burden of ECC.

Treatment options of ECC range from prevention, minimally invasive approaches to extraction depending on the extension of the caries. As ECC is monitored during early childhood, children in this age group may exhibit behavior problems during dental treatment. Pharmacological behavior control methods such as sedation and general anesthesia may be required.

The objective of this chapter is to make an update of ECC which is a persistent and possibly widespread public health problem. The diagnosis, epidemiology, etiology, preventive strategies, and treatment options of ECC are reviewed.

2. Early childhood caries (ECC)

2.1. Diagnosis and classification of ECC

The lesions progress rapidly; they can be extensive and typically affect free smooth surfaces such as the labial surfaces of maxillary incisors and lingual and buccal surfaces of maxillary and mandibular molars. ECC has a special caries pattern. The maxillary primary incisors are most vulnerable to the disease and are affected first. In the moderate stage, the caries begins to spread, and the buccal and occlusal surfaces of the primary molars and the buccal surfaces of the primary canine are affected, respectively, in a way that reflects the pattern of eruption. Usually the mandibular incisors are protected by the tongue and saliva [7, 8].

ECC initially presents as opaque white or brown spots on maxillary incisors along the gingival margin and the lesions often cover many surfaces in each of affected tooth. In severe cases, anterior teeth break down during eruption and the process continues with the mandibular molars [2, 7] (**Figure 1**).

Several research groups have attempted to develop classification systems for early childhood caries. Wyne A classified ECC based on the severity and etiology, as Type I (from mild to moderate), Type II (moderate to severe), and Type III (severe). The existence of "isolated carious lesion(s)" involving incisors and/or molars is classified as Type I; labiolingual lesions affecting maxillary incisors, with or without molar caries, depending on the age of the child and stage of the disease, are classified as Type II; carious lesions affecting almost all teeth including the mandibular incisors are classified as Type III. Johnston T, Messer LB, classified ECC based on the pattern of ECC presentation. Lesions that are associated with developmental defects (pit and fissure defects and hypoplasia) are classified as Type I; smooth surface lesions (labial-lingual lesions, approximal molar lesions) are classified as Type II; rampant caries—having caries in 14 out of 20 primary teeth, including at least one mandibular incisor—are classified as Type III [2, 9–11].

2.2. Epidemiology of ECC

ECC still remains a serious challenge for health care providers, despite the improvement in dentistry practice and decline in the prevalence of dental caries [11]. The prevalence of ECC differs according to the examined groups' age, affected teeth, socioeconomic status, lifestyle, dietary pattern, oral hygiene practices, behavioral factors, race, culture, and ethnicity which differ from country to country [2]. The prevalence of ECC is reported as between 1% and 12% in most developed countries [12] and 85% in disadvantaged groups in developing countries [13]. In a systematic review, it is presented that the prevalence of ECC varies from 2.1% in Sweden to 85.5% in rural Chinese children [14]. Some of the highest prevalences of ECC have been reported in some Middle Eastern countries, such as Palestine (76%) and the United Arab Emirates (83%) [15, 16]. Increases in caries prevalences among 2–5-year-olds are reported, respectively, from children in Brazil, North America, China, Australia, and Korea, with the

Figure 1. Intraoral images of the severe ECC.

prevalence rates of 27, 60, 67, 80, and 83.3% [17, 18]. Turkey is a developing country; therefore, there is a lack of data about the prevalence of ECC in Turkey. Only two articles are presented about this topic. Gökalp et al. [19] presented a national epidemiologic data which showed that the caries value and prevalence rates were 3.7 and 69.8% for 5-year-old children and 1.9 and 61.1% for 12-year-old children. Doğan et al. [20] presented the regional ECC prevelence in the city center of Kırıkkale, Turkey, as 17.7% in a group with the mean age of 25.8 ± 10.11 months. To realize the severity and extent of the disease, a comprehensive study supported by health ministry is needed in Turkey.

2.3. Etiology of ECC

The etiology of ECC is obviously multifactorial and can be viewed from multiple standpoints: molecular/biochemical, microbiological, behavioral, social, health system, and even political [21].

Dental caries arise from the interaction of various etiological factors. Cariogenic microorganisms, fermentable carbohydrates, and susceptible tooth surface/host are the main factors. Factors such as high sugar intake, lack of oral hygiene, lack of fluoride exposure, and enamel defects are some of the major factors and responsible for the development of ECC [22, 23]. Low socioeconomic status, sociocultural differences in oral health, beliefs and practices, minority status, low birth weight, and transfer of microorganisms from mother to child are some of the multitude risk factors documented in epidemiological studies [24, 25]. To understand the complex nature of ECC better, further studies are required.

2.3.1. Diet

There are many risk factors associated with ECC. It is a dynamic pathological process that depends on biofilms, diet, and host salivary constituents. Dietary practices; poor dietary habits and food preferences (including starches and other sucrose-containing foods), frequent exposure to sweet beverages, and night-time meals or drinks promote the proliferation of cariogenic bacteria [26, 27].

Inappropriate feeding practices, such as bottle feeding with sweetened milk or fruit juice, night-time bottle feeding, and sleeping with honey-soaked dummies, have been associated with the initiation and development of caries in children [6, 8]. Inappropriate feeding practices can prolong the exposure of teeth to fermentable carbohydrates; *Streptococcus mutans* converts fermentable carbohydrates into acids, and demineralization starts.

Despite benefits of breastfeeding for systemic health, a well-known effect on ECC is controversial. In one of the systematic reviews, breastfeeding over 1 year beyond tooth eruption has been found to be associated with ECC [6]. The World Health Organization (WHO) recommends exclusive breastfeeding until the age of 6 months, and breastfeeding complemented with food intake is suggested until the child becomes 2 years old [28]. Current scientific evidence suggests that breastfeeding has a greater protective effect against dental caries than bottle feeding, although the proper duration of breastfeeding analyzed in the studies could not be determined [29]. Cultural and social factors directly affect the practices such as prolonged

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breastfeeding and sharing the mother's bed. In the systematic review, no association was reported between breastfeeding duration, sharing bed, and ECC, whereas a strong association was determined with nocturnal breastfeeding. They concluded that children who were breastfed more than twice at nights after age of 1 year had a much higher risk of having ECC [6]. Frequency and duration of exposure are critical at this point, but the caries experience also correlates often with social and other behavioral factors within the family [8].

Breastfeeding should be encouraged in accordance with WHO recommendations but to prevent ECC, regular mechanical removal of the dental plaque should be satisfied and parents should stop breastfeeding at nights [29]. Behaviors like limiting added sugar, reducing bottle use, and serving defined meals or snacks have positive implications for oral health. If the baby awakens at night, and has difficulties on leaving his/her behavior about nightfeeding, water should be preferred over milk or juice. Snacking frequency should be limited (no more than two or three snacks per day) to prevent decaying.

According to the European Academy of Peditaric Dentistry (EAPD)'s guidelines on the prevention of ECC, frequent intake of sweet drinks and feeding with sweetened baby bottles on demand should be discouraged, especially at nighttime. It is recommended with the evidence level grade C [30].

2.3.2. Cariogenic microorganisms

Cariogenic bacteria were shown to be a significant risk factor for ECC. The pathophysiological etiology of ECC is associated with early colonization and high levels of the cariogenic microorganisms (e.g., *Streptococcus mutans* (SM) and *Streptococcus sobrinus)* and abundance of dental plaque as a consequence of overexposure to sugars and complex interspecies with accumulation of salivary proteins and adhesive glucans. The acidic environment in the dental biofilm causes demineralization of the enamel and dentin [27, 31].

Since cesarean deliveries are more aseptic than vaginal deliveries, infants delivered by cesarean section acquire SM earlier and the atypical microbial environment increases the chances of SM colonization [32]. Bacteria that present in the predentate stage play a significant role in early caries experience [6].

SM is the main bacteria that have strong association with ECC whereas other oral bacteria in the dental biofilm could be involved in the initiation and progression of caries [26]. Another bacterium associated with ECC development is *Lactobacillus* (LB) species, which play an important role in lesion progression [31]. The *Actinomyces* species, especially *Actinomyces gerencseriae*, were also associated with caries initiation. On the other hand, *Bifidobacterium* species were linked with deep caries lesions. There are also a few non-mutans streptococci which have acidogenic and aciduric attributes, related to dental caries. Epidemiological data suggest that in the pathogenesis of dental caries *Candida albicans* also plays an active role [2]. The evidence presented in the systematic review indicates that the prevalence of *C. albicans* in children with ECC is significantly higher than in caries-free children. In addition, it is stated that children with oral *C. albicans* have higher odds of experiencing ECC compared to children without *C. albicans* [33].

However, MS levels in plaque vary depending on the stage of caries development and dietary habits, infant feeding practices such as frequent exposure to sugar, frequent snacking, taking sweetened drinks to bed, sharing foods with adults, as well as maternal caries status and oral hygiene [34].

ECC is an infectious, transmissible disease. SM is the main bacteria in ECC pathogenesis and these bacteria can be transmitted from mother to child and/or also from other primary caregivers. That is commonly termed as "window of infectivity" [35]. It's known that children who have higher SM levels were five times more prone to have dental caries [23]. The major source of acquiring the SM in children is mainly from their mothers during first 12–24 months via vertical transmission through saliva. Maternal factors such as poor maternal oral hygiene maintenance, frequent snacking, and sugar exposure were shown to influence bacterial acquisition. However, antibacterial treatment of only mothers or children may not be sufficient to reduce infection [36]. Children can be infected with mutans streptococci horizontally between siblings and caregivers [37].

It is well known that saliva and dental biofilm harbor different genotypes of *S. mutans*. However, it is still unknown if genotypic diversities and phenotypic traits of *S. mutans* are related to different caries status or caries severity in children [38]. Regardless of caries status, the genotypic diversity of *S. mutans* was determined to be similar. In addition, *S. mutans* genotypes from caries-active children were found more acid tolerant and presented higher ability to form biofilms than those isolated from caries-free children. The most important *S. mutans* trait related to the pathogenesis of sECC is thought to be tolerance to acid [39].

2.3.3. Environmental factors

ECC is a global dilemma, and with the exception of a multitude of risk factors like oral hygiene maintenance, its incidence is associated with additional factors, such as socioeconomic and education status [40]. ECC prevalence in non-industrialized and industrialized countries has reported between 28 and 82% [6]. It is emphasized that children, who are two times more likely prone to dental caries, are from low socioeconomic status [41].

The use of caries-promoting rearing practices was associated with sociodemographic factors such as family income, poverty, ethnicity parental education, number of children that families have, and rural or urban residence [6]. Lack of good oral hygiene practices and lifestyle factors promote the development of ECC. Children should begin receiving oral hygiene care since the eruption of the first primary tooth.

Prenatal conditions such as premature birth and low birth weight are described as some risk factors that could promote the presence of enamel hypoplastic defects [42]. Enamel hypoplasia was reported in 67% of children who have low birth weight in comparison to 10% among children with normal birth weight, in a case–control study [43]. The causal relationship of enamel hypoplasia with dental caries has not been established [2].

According to SIGN 18 recommendations (grade D), when developing community preventive programs, children from low socioeconomic status groups should be considered to have increased risk for ECC [44].

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2.3.4. Teeth

Dental caries is etiologically heterogeneous but mostly behaviorally driven; half of its observed variance may be attributed to predisposing genomic factors [45]. Since the late 1950s, dental caries has been shown to have a substantial genetic component [46]. Genomics likely influences ECC, susceptibility via control of dental anatomy, enamel quality, salivary properties, immunity, oral microbiome composition, taste preference, and other intermediate characteristics [45]. Recent studies have been designed to validate genetic susceptibility to dental caries in children. It is thought that the developments in this area may be an important step for determining the dental caries risk and prevention.

3. Risk assessment update in ECC

As ECC is a highly complex disease, identification of children at risk for ECC before the onset of cavitation remains challenging. There are gaps in the knowledge as to the answers of the following questions: how the risk factors interrelate and why some children suffer a greater burden of disease than others [26]. This limitation is due to the multifactorial (environmental, social, and behavioral) nature of ECC and the limited accuracy or poor validity of existing caries risk screening tests [44]. Up to date, no effective methods in identifying the risk factors of ECC development are presented. In the near future, identification of biomarkers and development of biology-based analytical tools or devices for caries risk assessment would be available. For providing greater predictability of ECC development and improving the accuracy of the existing ECC-risk screening methods, behavioral risk assessments should be combined with microbiome and salivary biomolecule analyses [26].

Recent studies are already focusing on this area. In this point of view, ECCs' relationship with microbial biofilm variability (focused on OMICS-based approaches, such as high-throughput (meta) genomics, transcriptomics and proteomics, as well as metabolomics), specific genetic influences, iron deficiency, prenatal maternal cigarette smoking, and so on is still being investigated. Therefore, further well-designed studies should be planned to get evidence-based results in this area.

Emerging biological insights about the pathogenesis of ECC can help to better understanding, provide personalized approach, provide enhanced preventive care for the susceptible children, and treat this early-onset, aggressive childhood disease. This approach ultimately helps to eliminate this costly and painful disease [26, 47].

For making a clear prediction, there is not any superior method and no evidence exists to support the use of one model, program, or technology over any other [48]. Although ECC prediction tools have limited practical clinical utility, they serve as a valuable resource in dental education and as guides for the development of public health programs [21].

Moderate-to-weak evidence supports the following recommendations that could be made: (1) Caries risk assessment of children should be carried out as soon as their first tooth erupts by dental professionals and this should be reassessed periodically over time; (2) while assessing caries risk in young children, multiple factors like clinical, environmental, and behavioral should be considered by interviewing the parents. Examples include caries experience, dietary habits, such as frequency of sugary food and drink consumption, socioeconomic status, oral hygiene habits, including use of fluorides, and medical history, with emphasis on conditions that could affect salivary flow rate. Considering the factors associated with the parents such as parental oral health status and parental deprivation, it is very important for assessing children's caries risk. (3) The use of structured forms, although with limited validity, may aid in systematic assessment of multiple caries risk factors and in objective record keeping. (4) Children from low socioeconomic status groups should be considered in increased risk of ECC when developing community preventive programs [44, 48].

4. Management of ECC

ECC affects children's physical (body weight, growth, etc.) and mental health and quality of life (eating, speaking, school attendance, and school performance, etc.) negatively [6]. A single and most powerful predictor for future caries experiences is accepted as past caries experiences. So, early and effective interventions are highly required for preventing ECC [8, 27]. The most effective approach for controlling ECC is based on prevention, not on restorative treatment through the epidemiological data [8].

It is recommended that routine community health awareness programs should be conducted to educate the public about the deleterious effect of ECC and also to emphasize the importance of dental routine check-ups. This may help prevent the disease and improve the quality of life of not only individuals but also their children [49].

There are some barriers in integrating oral health care into overall health care to prevent ECC. ECC prevention should be integrated into the primary care settings. Some strategies such as effective prevention, utilizing the support of professionals, integrated disease management, and innovative insurance structuring might develop to overcome these barriers [50].

A severe ECC experience is an important predictor for adult caries. Creating strategies to prevent and control ECC is important to improve general and oral health.

Primary prevention must start in the prenatal stage during pregnancy. The prevention process should progress through the perinatal period and continue with the mother and infant within the context of the family and then proceed during preschool programs.

Although maternal factors were shown to influence bacterial acquisition and modifying bacterial colonization in children, due to the complex nature of the disease, a relationship between vertical transmission of the bacteria and subsequent caries development in infants was not clarified yet. Further qualified studies are required to understand the complex nature of ECC better. In addition, in the systematic review written by Leong PM et al. [6], it is concluded that bacteria present in the predentate stage play a significant role in early caries experiences. So the pregnancy and the neonatal period are the important stages to identify 'at-risk' children and early maternal intervention can reduce the possibility of ECC.

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Prenatal visits, understanding the importance of regular examinations, especially before the age of 1 year, and brushing with fluoride toothpaste can be considered as important strategies for preventing ECC [27]. There are increasing evidences which suggest that the preventive interventions within the first year of life are critical. For an effective prevention of ECC, conducting a caries risk assessment and providing parental education within 6 months (but no longer than 12 months) of the child's first tooth eruption is recommended [3].

For reducing mother–child (vertical) mutans streptococci (MS) transmission, clinical and educational interventions should start during pregnancy [51]. For this reason, oral health screening, dental treatment, education on oral health hygiene, and supporting a non-cariogenic diet during pregnancy and perinatal period are the most important strategies that can assist in the prevention of ECC [2]. To promote maternal and infant oral health, anticipatory guidance should be a part of standard prenatal health care [51].

Management of ECC can be examined in two sections as preventive strategies and treatment of cavitated lesions.

4.1. Preventive agents

It is important to understand the natural history of ECC in order to implement effective preventive strategies. ECC disease has rampant, acute, and progressive characteristics and it is thought to be largely modulated by behavioral and environmental risk factors, such as diet and fluoride exposure [52, 53]. Early non-operative interventions done by dental professionals, including plaque removal, topical fluoride, and sealant applications, are accepted as the important steps to prevent ECC [50].

Several antimicrobial agents (e.g., fluoride, chlorhexidine, iodine, xylitol, silver compounds) combined with a range of application methods (e.g., mouth rinse, gel, varnish, cleaning wipe, restorative materials) have been used, with remarkable reductions in *S. mutans* and *S. sobrinus* levels [31].

The most commonly used preventive agents in management of ECC include application of fluoride gels, fluoride varnishes, sealants, chlorhexidine varnish, 10% povidone iodine, and xylitol oral syrup [27].

In order to arrest early childhood caries, topical applications of antibacterial agents such as chlorhexidine and povidone iodine are supported and recommended [27].

4.1.1. Fluoride

Fluoride is the most important strategy in the non-invasive management of dental caries. Using fluoride through gels, mouthwashes, and varnishes is a common application in prevention programs [54].

Fluoridated toothpaste is the most commonly used form of self-applied fluoride therapies for fluoride delivery, and its anti-caries effects are proven [55]. The formulation of dentifrice, brushing behaviors, frequency, time, and post-brushing rinsing practices are significant factors influencing its efficacy [56].

While starting to implement oral hygiene, agents should not exceed the time of eruption of the first primary tooth as AAPD recommends. Under the age of 3, toothbrushing should be performed with a smear or rice-sized amount of fluoridated toothpaste. For children aged between three and six a pea-sized amount of fluoridated toothpaste should be used [3]. As EAPD recommends, brushing teeth twice a day with a fluoride toothpaste could prevent ECC [48].

While EAPD [57] recommends brushing teeth with 500 ppm of fluoridated toothpaste, according to SIGN (2005) [58], teeth should be brushed with 1000 ppm of fluoridated toothpaste as soon as they erupt, regardless of age and risk for caries, with no rinsing. Only spitting is recommended. On the other hand, the Centers for Disease Control and Prevention (CDC) (2001) and Australian Research Centre for Population Oral Health (ARCPOH) (2006) recommends that children under the age of 2 years and 18 months, respectively, do not have to use fluoridated toothpastes. Caries risk assessments of these patients should be performed by a professional and those assessments should be taken into account to offer the right amount of fluoridated dentifrice. Brushing is essential and that should start as soon as teeth eruption and must be done by parents with a small quantity of fluoride-containing toothpaste [59].

Fluoride varnishes have been used at concentrations of 1% and 5% for the prevention of ECC. Cochrane systematic review stated that fluoride varnish is an effective way in prevention of ECC and reduces caries in the primary dentition by 33% [27]. According to evidence, fluoride varnish is considered as a safe and effective agent for caries prevention in young children [56]. EAPD policy document informs that professional applications of fluoride varnishes are recommended for groups or individuals who are carrying the risk of caries, at least twice a year (grade B) [31]. Additionally, Silver Diamine Fluoride (SDF) can be an option for keeping tooth decays under control. A total of 30 and 38% concentrations of SDF have potential to be a caries preventive treatment agent for primary dentition and permanent first molars. Standardized SDF protocols must be developed [60].

To reduce dental caries in preschool children, fluoride varnish applications that are made twice a year are recommended in conjunction with toothbrushing twice a day with a fluoride-containing toothpaste and dietary advice [56].

Moderate and limited quality of evidence in support of fluoride toothpaste and fluoride varnish for early childhood caries prevention is reported [54].

4.1.2. Other non-fluoride agents

4.1.2.1. Chlorhexidine

Chlorhexidine (CHX) is an antibacterial agent that is commonly used as an antiseptic. CHX is used at concentrations ranging from 0.1 to 40% in solutions, gels, chewing tablets, and varnishes. In one of the meta-analysis, the caries inhibiting effect of CHX was reported to be around 46% [61].

Chlorhexidine has a long history of use in caries prevention with conflicting results [27]. Some studies have found 0.12% of chlorhexidine gluconate efficacious with multiple applications, already with synergic effects in combination with fluoride therapy. A clinical study performed with children supported this hypothesis and it was reported that separate application of the chlorhexidine varnish and fluoride varnish was not effective as a combination of the agents in enhancing the remineralization of white spot lesions after 3 months [56].

4.1.2.2. Xylitol

Xylitol is a five-carbon sugar alcohol and therefore it is a good sugar substitute and has sweet taste. It is non-acidogenic, meaning not metabolized by the cariogenic bacteria. It has anti-bacterial properties. Salivary flow rate and buffering capacity can be increased with xylitol. Xylitol arrests the dental caries and helps remineralization [27]. AAPD supports the usage of xylitol as a non-cariogenic sugar substitute. Xylitol is available in many forms (e.g., gums, mints, chewable tablets, lozenges, toothpastes, mouthwashes, oral wipes) [62].

Xylitol showed better results in the reduction of the incidence of caries by decreasing the MS levels in children and maternal transfer from mother to their children [27, 62].

AAPD recommends xylitol syrup (3–8 grams/day in divided doses) to children under the age 4 years and chewing gum, mints, and lozenges (3–8 grams/day in divided doses) to children 4 years of age or older at moderate or high caries risk [62].

- Daily xylitol-wipe application significantly reduced the caries incidence in young children as compared with wipes without xylitol.
- Chewing xylitol-containing gums during the period of primary teeth eruption (6–20 months) may reduce caries in the primary dentition [27].

4.1.2.3. Casein phosphopeptide-amorphous calcium phosphate (CPP-ACP)

One of the calcium-phosphate-based remineralization systems is CPP-ACP which is a bioactive material with a base of milk products. It can provide calcium and phosphate ions in the dental plaque, buffering plaque acidity (pH) and enhancing the remineralization process. In addition, it can participate in the pellicle structure and prevent the adhesion of cariogenic Streptococci to tooth surfaces [63]. CPP-ACP is used as an adjunct preventive agent in patients at a high risk for caries. CPP-ACP is available in the form of chewing gums, mouthwashes, and dental creams. A recent systematic review showed that even though the CPP-ACP seems insignificantly different beside fluorides, it has a remineralizing effect on early caries compared to control or placebo groups. Although some of the studies have shown a synergistic effect of CPP-ACP and fluoride on remineralization, the advantage of it is still controversial when it is used as a first choice supplement instead of fluoride. To confirm the effectiveness of non-fluoride agents, high-quality clinical trials are required while controlling dental caries of preschool children [56].

4.1.2.4. Povidone iodine

Povidone iodine is a solution that releases iodine slowly which has long-term antimicrobial action. It is used as a topical agent in prevention of ECC. Several studies searched the effect of regular applications of 10% povidone iodine and concluded that periodic topical applications reduce risk for ECC development by suppressing the level of *S. mutans* [27].

4.1.2.5. Probiotic supplements

Probiotics are described as viable microorganisms and provide health benefits on the host when used in enough amounts. Most commonly investigated strains belong to the *Lactobacillus, Streptococcus,* and *Bifidobacterium* genera as regards probiotics. Within the oral cavity, mechanisms of probiotic action can be explained in two ways as the first as direct interactions with dental plaque by replacement therapy and the second as modulation of both innate and adaptive immune function [64].

In one of the reviews, searching about the prevention effect of probiotic bacteria on ECC suggested that probiotic supplements were better than placebo but concluded that the quality of the evidence was low or very low [65].

The existing evidence supporting the use of silver diamine fluoride, xylitol, chlorhexidine varnish/gel, povidone iodine, remineralizing agents (e.g., casein phosphopeptide amorphous calcium phosphate), and probiotic bacteria for ECC prevention is considered insufficient [54].

Although there is also insufficient evidence for using sealants to reduce incidence of ECC, EAPD recommends fissure sealant application to arrest non-cavitated occlusal caries [48, 54].

4.2. Management of cavitated ECC

Although there is insufficient evidence for a traditional restorative approach to the management of caries in the primary dentition; it is well-known that untreated ECC can cause increased treatment costs, delayed physical growth and development, diminished ability to learn, and diminished oral health-related quality of life [54]. Restorative care in the primary dentition is essential for making a significant difference on psychological and social aspects of the child's life.

Although there is insufficient evidence to make recommendations about which material and technique is the most appropriate for restorative treatment in young children, minimally invasive approaches are accepted as advantageous [66].

Atraumatic restorative treatment (ART) was initially developed to provide effective restorative treatment of cavitated ECC, in developing countries where electricity may not be available [66]. ART is a pain-free restorative procedure, low cost, and can be applied outside the clinical setting or when conventional treatment is not available. It involves no local anesthesia or drilling. Caries removal is done by using hand instruments and followed by a restoration with highly viscous glass ionomer cement (GIC). A disadvantage of this treatment is its high rate of failure. Minimally invasive approaches with ART with highly viscous GIC provide some evidence that is beneficial in managing decayed primary teeth. To provide more information on restorative and clinical outcomes of the ART-based approach, further studies with a longer follow-up should be undertaken [67, 68].

New dental materials and techniques for restoring decayed teeth have been developed. However, despite much improvement in dental materials, the failure rates of amalgam, composite fillings and glass ionomers were reported almost at the rate of 58%, 62%, 77%, respectively, over five years. For making decisions to determine the appropriate choice for dental practitioners, limited evidence exists. Primary teeth after pulp therapy or multiple carious surface lesions are generally recommended for restoring with stainless steel crowns. The

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Hall technique that involves sealing the carious lesions of primary molars with stainless steel crowns without caries removal and crown preparation has been proposed as a modified technique for stainless steel crowns. The adoption of this technique in a community-based program is considered to be so difficult because of material prices and the operation time required [56].

5. Conclusion

ECC is the most common chronic disease among young children and affects children less than 71 months of age, and they currently represent a public health problem in various countries worldwide. There are a multitude of risk factors associated with ECC. Feeding habits and a variety of biological, environmental, and socioeconomic factors are involved in the development of ECC. It can affect a child's well-being, learning ability, and quality of life. It is important to understand the natural history of ECC in order to implement effective preventive strategies. Evidence of effective ECC prevention suggests prenatal and immediate postnatal interventions. Health care professionals should carry out children's caries risk assessments in their first year as part of the children's overall health assessments and children should be reassessed periodically over time. Population-based early childhood health systems hold great potential to reduce the burden of ECC, improve health care efficiency and cost-effectiveness. Early non-operative interventions by the dental professionals, including plaque removal, application of topical fluoride, and usage of sealants, are accepted as important steps for preventing of ECC. Cavitated ECC should be treated restoratively, although there is insufficient evidence to make recommendations about which material and technique is the most appropriate. Restoring is essential for making a significant difference on psychological and social aspects of the child's life.

Conflict of interest

None declared.

Notes/thanks/other declarations

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Author details

Arzu Pinar Edem

Address all correspondence to: apinar@istanbul.edu.tr

Department of Pedodontics, Faculty of Dentistry, Istanbul University, Çapa, Fatih/Istanbul, Turkey

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Caries Diagnosis Aided by Fluorescence

Laurence J. Walsh

Additional information is available at the end of the chapter

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Abstract

Because of the limitations of visual inspection and dental radiographs for detecting early or hidden forms of dental caries, much effort has been expended developing additional methods to supplement traditional examination, Foremost amongst these has been fluorescence, which exploits the light emitting properties of bacteria deposits or of normal tooth structure. Key considerations when using fluorescence are the differences between the light emitting properties of carious versus sound tooth structure, the excitation wavelengths of light that are chosen, and the methods used to analyze fluorescence emissions. Provided that technical issues such as false positive and negative signals can be addressed, devices that employ fluorescence can improve the detection and management of dental caries, and help guide the removal of carious tooth structure during restorative procedures. Clinical recommendations for using fluorescence as an aid to caries diagnosis are based on appreciating the effects of moisture, stains, and quenching agents on readings, and altering the ambient light conditions to maximize the signal to noise ratio. Any quantitative fluorescence techniques require calibration of the device, and checks for contamination of the optics. Differences in the performance of fluorescence devices must also be considered when comparing results against thresholds for intervention.

Keywords: fluorescence, porpyhrin, QLF, DIAGNOdent, caries detection, caries removal

1. Introduction

The clinical diagnosis of caries is an imperfect process. As well as examining the enamel and root surfaces of teeth, clinicians must inspect the margins of restorations and sealants, and around brackets and other devices attached onto teeth that hinder plaque removal and make the development of caries more likely to occur. Further problems arise when the tooth surface is broken and restorative intervention is needed, since professional judgment around the extent of removal of carious tooth structure is needed.

2. The need for adjunctive methods

The limited performance of traditional mirror and probe examinations for dental caries is well known [1–4]. For fissure caries diagnosis, conventional approaches can easily overlook small lesions. In the primary dentition, a conventional visual-tactile technique will miss 38% of occlusal caries, including lesions of "hidden" occlusal caries that reach dentine. Such lesions are sufficiently large and demineralized enough to be detected on bitewing radiographs. These occur at a prevalence of which has a prevalence of between 4 and 15% [5, 6]. Likewise, for primary molar proximal surface caries, a visual-tactile examination will miss 57% of carious lesions that require restorative treatment [7].

The limitations of visual methods for detecting carious lesions were highlighted in a recent analysis of 102 studies, which reported that specificity values ranged from 0.573 to 0.992, with sensitivity values from 0.274 to 0.77 [8]. One can conclude that visual examination for dental caries is a useful method that is used widely, but it is imperfect [9].

Radiographs are also imperfect as a diagnostic approach, since small lesions are not shown. In a clinical study of 481 children aged 5–12 years attending a school-based dental clinic, only 40 out of 96 teeth that were clinically scored as showing dentine caries (42%) had dentine radiolucencies on the bitewing radiographs [10]. Likewise, in a recent meta-analysis, for the detection of any kind of proximal lesions the sensitivity of bitewing radiographs in 24 clinical studies was 24% (CI 21–26) and the specificity was 97% (95–98) [11]. This is why patients with high caries risk need to be examined with other more sensitive methods, rather than just relying on radiographs alone.

This chapter examines the development and deployment of adjunctive approaches to caries diagnosis using fluorescence. This approach has applications for early diagnosis, enabling pre-white spot lesions and white spot to be identified and assessed, so that remineralization of these lesions can be undertaken. Moreover, when restorative intervention is needed, fluorescence can be used to guide the removal of caries from the tooth, so that sound tooth structure is spared.

2.1. The process of fluorescence

Fluorescence is one of a number of processes by which materials can emit light after appropriate activation. A key feature of fluorescence is that the emission of light matches the mode of excitation, so if the light is pulsed in a particular way, the same pattern will be seen in the fluorescence emissions. When light is absorbed into a fluorophore, the molecule becomes electronically excited to higher energy levels, from where decay to lower energy levels occurs by emitting radiation and thermal relaxation. The intensity of the emission is linearly proportional to the concentration of the fluorophore present in the target, making fluorescence very useful for quantification.

Because of the difference in energy, the color of the emitted fluorescence light is always different that of the excitation light, having a longer wavelength and a lower photon energy. Thus, violet or blue excitation light will give emissions that are green, orange or red, all of which are longer wavelengths of visible light (**Table 1**). Likewise, visible red excitation will give emissions in the near infrared region. This relationship is known as the Stokes' shift [12, 13].

2.2. 405 nm violet light and the excitation of bacterial porphyrins

Protoporphyrin IX and similar porphyrin molecules such as coproporphyrin are derivatives of hemoglobin, and are involved in the biosynthetic pathway for heme. Porphyrin derivatives are not present within normal healthy tooth structure, so are a useful marker for bacteria associated with dental caries. Fluorescence excitation for these fluorophores occurs strongly in the visible violet-blue range, and especially between 390 and 420 nm, with maximum excitation at around 405 nm [14–16].

Violet light (405 nm wavelength) gives strong emissions from many bacterial species involved in the caries process. Lactobacilli, which are secondary colonizers of carious lesions, are stronger emitters of visible red fluorescence than are mutans streptococci. *Actinomyces odontolyticus* has strong porphyrin fluorescence [17]. The fluorescence characteristics of individual bacterial species vary according to the nutrients present in their environment, such as blood and associated metalloporphyrins [18]. Nevertheless, red light emissions under violet light excitation are well suited for the detection of key cariogenic bacteria [19].

Because of this feature, 405 nm violet light emitting diodes (LEDs) have become a preferred illumination source, and these have been used in a range of adjunctive devices for caries detection, including intra-oral cameras, stand-alone illuminators and dental high speed handpieces (**Table 2**).

As well as caries detection during dental examination, a further application which has emerged for such devices (discussed later in this chapter) is the use of fluorescence to guide the dental practitioner during cavity preparation in the selective removal of infected dentine.

The same caries detection devices can also be used to detect and assess mature deposits of dental plaque biofilm more than 24-h-old, as these have high levels of porphyrins and give strong red fluorescence when excited by violet light [20–22]. Higher levels of porphyrins are found in biofilms associated with bleeding gingival sites where bacteria are present that metabolize heme [23].

Target	Excitation (nm)	Emission (nm)
Protoporphyrin IX	407	590
		620
		635
Mature dental plaque	400–500	600–700
	655	720–800

Table 1. Typical fluorophores of interest in caries diagnosis.

Intra-oral camera	Penscope™	Morita Corp., Kyoto, Japan
	PenViewer™	Morita Corp., Kyoto, Japan
	G-Cam™	GC Corp., Tokyo, Japan
	VistaCam®	Durr Dental, Bietigheim-Bissingen, Germany
	VistaCam ix Proof™	Durr Dental, Bietigheim-Bissingen, Germany
	Cam X Spectra	Air Techniques, Melville NY, USA
Illuminator	SiroInspect™	Sirona, Bensheim, Germany
	QLF-D Biluminator 2 + ™	Inspektor Research Systems,
		Amsterdam, The Netherlands
Dental handpiece	Fluoresce HD™	Lares Research, Chico, CA, USA.

Table 2. Caries detection systems using 405 nm violet light.

When using 405 nm violet light in the clinical setting, drying tooth surfaces or, conversely, the presence of saliva over a tooth surface, do not affect the red fluorescence emissions from bacterial porphyrins in carious lesions or from dental plaque [24]. However, fluorescence readings are altered when visible traces of blood appear in the saliva because the patient has gingivitis. This confounding factor needs to be considered when examining teeth in areas where gingivitis is present.

2.3. QLF and the assessment of enamel mineral loss

Quantitative light-induced fluorescence (QLF) is based on the principle that as a tooth develops dental caries, the green fluorescence of normal enamel that is emitted under illumination with short wavelength (violet-blue) light reduces, making white spot lesions that are below the normal diagnostic threshold become visible.

Healthy teeth with no enamel lesions fluoresce green in a consistent even manner. This feature of human teeth has been known for more than 100 years. The organic (protein) components of tooth structure are responsible for this, and certain fluorophores such as the amino acid tryptophan account for the normal fluorescence of sound dentine when exposed to violet or ultraviolet light. As caries develops in enamel there is marked reduction in green fluorescence, mostly because of changes in light scattering properties as the mineral content reduces and the water content in the enamel rises. This phenomenon was observed at the Karolinska Institute in Sweden in the late 1970's and was characterized using laser light as the excitation source in the early 1980s [25–27].

When caries develops in the enamel, less of the incident violet-blue light reaches the dentino-enamel junction, which is where a high concentration of fluorophores is present that emit green light. Using this approach, fluorescence photographic or video (frame grabber) images of enamel surfaces that have white spot lesions can be digitized, and the difference between these areas and adjacent normal enamel on the same tooth (i.e., fluorescence loss) quantified

[28]. The extent of fluorescence loss correlates strongly with mineral loss within the enamel as assessed using transverse microradiography and other methods, making QLF a sensitive and valid method for quantifying mineral loss in carious lesions in the enamel [29, 30].

A significant decrease in the intensity of the green fluorescence signal occurs in both demineralized sites and in areas where there is caries in the dentine [27, 31, 32]. A reduction in green fluorescence from the enamel is also seen in conditions where the composition of the enamel is altered, such as in fluorosis or when interruptions to tooth formation occur during tooth development. In the case of dental fluorosis or enamel formation defects, the shape and location of these areas are quite different from those of dental caries [33].

QLF has been used in both laboratory and clinical studies to assess mineral loss and mineral gain in various caries models and in high caries risk patients, respectively. The method shows good agreement with other fluorescence-based approaches [34–36]. In terms of benefits for clinicians, QLF can detect about twice as many demineralized pre-cavitated enamel areas (pre-white spot lesions and white spot lesions) as a conventional visual examination [37]. In addition to enamel on smooth surfaces, QLF can also be used to examine interdental areas. Care must be taken to optimize the angulation at which the teeth are viewed [38, 39].

QLF has been undertaken using the argon ion laser (wavelength 488 nm) and blue diode lasers (wavelength 470 nm), however most devices used for QLF have employed a lamp with blue-violet emissions as the light source (e.g., Inspektor™ Pro, Inspektor Research Systems BV, Amsterdam, The Netherlands). The more recent version of this technology uses an array of LEDs (QLF-D Biluminator 2+, Inspektor Research Systems). In these systems, a camera collects fluorescence emissions that have been filtered through a high-pass filter (wavelengths >520 nm). Image analysis is undertaken on a personal computer using purpose-designed software, such as Inspektor C4 QLF Research Suite. For calculating fluorescence loss, the fluorescence of sound enamel at the lesion site is reconstructed from the fluorescence of sound enamel bordering the lesion. The error of using this reconstruction approach has been shown to be very small (mean difference 1.6%), over areas up to 14 mm^2 [29].

2.4. 655 nm red light excitation and the DIAGNOdent

The DIAGNOdent (Kavo, Biberach, Germany) uses pulsed visible red light (wavelength 655 nm) to elicit fluorescence from bacteria and their products, in the near infrared range. The device provides readings of fluorescence intensity on a scale of 0–100 [40]. The DIAGNOdent Classic detects porphyrin derivatives with a detection limit in the order of 1 picomole [41]. While many Gram negative bacteria are strongly fluorescent, the DIAGNOdent can also detect planktonic species as well as biofilms of mutans streptococci [42].

DIAGNOdent technology exists in three physical forms: the DIAGNOdent Classic, the DIAGNOdent Pen, and the KEY-3 laser. In the latter, the fluorescence system is integrated into an Er:YAG treatment system and used to selectively fire the treatment laser as a type of guidance or autopilot system.

The emitted fluorescence light, for example from lesions deep in fissures or at the dentino-enamel junction, is detected readily because enamel has high transparency in the near infrared region [43]. This makes the DIAGNOdent useful for detecting lesions in dentine that are not visible on clinical examination but may be seen on radiographs (if these were taken). Thus, when bitewing radiographs are not be taken, the diagnosis of occult dentinal caries may be further enhanced by using the DIAGNOdent at recall examinations [44].

A major application of the DIAGNOdent is screening occlusal surfaces for caries that has reached the restorative threshold of the dentino-enamel junction. This method works well in both primary and permanent teeth [45–47]. Applications of the DIAGNOdent extend beyond the detection of fissure caries to include the monitoring of non-cavitated incipient lesions, both in the enamel and on the root surface [48]. In such clinical applications, it is important to remember that the various DIAGNOdent systems assess the presence of bacteria, and not the level of mineral in the tooth structure per se [49].

Because of the high reproducibility of DIAGNOdent readings and consistency between devices of the same type produced over successive years, one properly calibrated DIAGNOdent device may be replaced by a new one without introducing errors [50].

The DIAGNOdent can be used to examine smooth surfaces of teeth. Validation of the DIAGNOdent Classic unit for quantification of lesions, comparing the results to histopathological and microradiographic analyses as a gold standard, had produced non-linear (rank order) correlation coefficients between lesion depth and DIAGNOdent readings of between 0.78 and 0.85, with very high inter- and intra-examiner agreement (0.94 and 0.95) [51]. Likewise, high levels of performance for detection of smooth surface caries have also been shown for the DIAGNOdent Pen, which gives similar (but not identical) readings [52, 53].

2.4.1. DIAGNOdent assessment of white spot lesions

In white spot lesions, bacterial products such as porphyrins become trapped in areas of porosity on the surface. When all overlying dental plaque biofilm is removed by professional cleaning, the retained bacterial products can still be detected. When DIAGNOdent readings trend upwards over time, this is closely associated with white spot lesions that eventually break down to form a cavity. Conversely, stable DIAGNOdent scores over prolonged periods of time are associated with stability and are a feature of arrested white spot lesions [54].

2.4.2. Performance of the DIAGNOdent

An important issue when using a DIAGNOdent is applying the appropriate cut-off levels to distinguish between sound and carious tooth structure, since this will influence the decision of the clinical operator to follow a remineralization approach, or to intervene restoratively. A number of threshold values have been stated in the literature, which take into account the normal background readings of sound tooth structure. A DIAGNOdent reading of five or less is typical for normal healthy enamel and dentine.

A recent systematic review of the performance of DIAGNOdent in laboratory settings included 39 studies. The pooled sensitivity was 0.71 (CI 0.69–0.73), and the specificity was 0.81 (0.73, 0.82). For the receiver operating characteristic curve, the area under the curve was 0.865, signifying strong performance. The conclusion from this meta-analysis was that laser fluorescence had the ability to diagnose occlusal caries lesions in permanent teeth and enamel and dentine caries [55].

Overall, when the DIAGNOdent Classic is used for caries detection, it gives a superior sensitivity over traditional methods, since small hidden lesions can be detected. The challenge in using the device comes from the fact that specificity values can be lower, particularly when the problems of false positive readings are not addressed [56]. Plaque that remains in a fissure will give a positive reading for fluorescence, and will compromise correct diagnosis of caries at that site [57]. Likewise, if extrinsic stains are present on teeth (e.g., from red wine), DIAGNOdent scores will rise on both the stained surfaces of enamel and on stained surfaces of restorations. The latter could lead to false-positive diagnoses of secondary caries. For this reason, restoration margins should be polished prior to DIAGNOdent measurements being taken [58].

Care should be taken when selecting a polishing paste, since some pastes can have fluorescence properties and thereby interfere with taking accurate DIAGNOdent readings [59]. This can be checked for easily by testing samples of the polishing material dispensed onto a mixing pad on the bench with the DIAGNOdent.

Assessment of the possibility of dental caries underneath sealants with DIAGNOdent is influenced by the filler content, opacity and intrinsic fluorescence of the sealant. Clear sealants will attenuate DIAGNOdent readings less than opaque sealants. Likewise, filled sealants attenuate readings more than unfilled sealants. The presence of titanium dioxide (added in to make the material have a white color) can cause intrinsic fluorescence, and also interfere with transmission of fluorescence emissions through the sealant. For these reasons, the use of DIAGNOdent to assess caries under dental sealants is not reliable as readings are likely to be inaccurate [60].

Clinical recommendations for using the DIAGNOdent are summarized in **Table 3**. This also includes general points that apply to all caries detection devices based on fluorescence.

2.4.3. DIAGNOdent pen

Following the release of the DIAGNOdent Classic in 1998–1999, the Pen version followed in 2005. It is much smaller size and better battery life was due to a change in the digital display from LEDs to a liquid crystal display. As with the Classic, the DiagnoDENT pen gives a variable pitch acoustic tone, and records both the more important "peak" fluorescence score as well as the momentary score.

The DIAGNOdent Pen can take a range of different tips. A conical tip is used for assessing fissures, and this is used in the same manner as the "A" tip of the DIAGNOdent Classic. A tip designed for the assessment of approximal enamel surfaces has a bevel that directs and collects the light at an angle of 100 degrees, which effectively functions like a periscope, allowing the approximal enamel surface of one posterior tooth to be assessed. The periscope tip has a marking to show which direction it is facing (mesial or distal). If a cavitation is present, not only will bacterial products be present in the tooth structure, they will also be present in high concentrations in the dental plaque biofilm inside the cavity. This gives a strong fluorescence emission and a high reading, which helps the clinician an answer to the important question of whether the surface is cavitated or not.

Remove all stains and dental plaque from the teeth, using a non-fluorescing cleaning agent
Remove excess moisture, but do not over-dry the teeth. Traces of saliva are acceptable, but there must not be any blood present over the surface.
Be aware of extraneous bright light sources such as direct sunlight that may affect the teeth. For some devices, turn off the operatory light to improve contrast.
Be aware of endogenous fluorescence of restorative materials, and variations in fluorescence with teeth in the one dentition
Teeth with discoloration from first and second generation tetracycline antibiotics will have elevated background fluorescence
Hold the tip against the surface
Keep the optical components (windows, tips, etc.) free of all contamination
* Correctly calibrate the fluorescence system as per the manufacturer's instructions
* If making fluorescence measurements, do not do this immediately after the application of oxidizers or other quenching agents
* Take measurements at least twice and record the maximum value
* Do not attempt to quantify fluorescence under sealants
*= requirements for quantitative systems, e.g., DIAGNOdent.

Table 3. Clinical recommendations for using fluorescence as an aid to caries diagnosis.

The diagnostic accuracy of the DIAGNOdent Pen for detecting approximal caries lesions, in posterior primary teeth and permanent teeth, at the cavitation and non-cavitation thresholds, is superior to digital bitewing radiography [61, 62]. In a recent study, the optimal fluorescence cut-off values with the DIAGNOdent Pen for detecting approximal caries lesions were 8 for non-cavitated lesions, and >16 for cavitated lesions. For cavitated lesions on approximal surfaces, the reported performance values were 100% for sensitivity, 85% for specificity and 95% for accuracy (based on the area under the receiver-operating characteristic curve). For non-cavitated (white spot) lesions, these metrics were 92, 90 and 95%, respectively [63].

Both the DIAGNOdent Classic and Pen systems use the same basic design, and one would expect that their performance (once they are properly calibrated) would be identical. In fact, variations in performance occur between them, with the Pen being more sensitive [64–66].

2.4.4. DIAGNOdent and assessing the extent of caries removal

Studies using extracted teeth with frank cavitations and stepwise caries removal using a range of methods have shown that DIAGNOdent values reduce during caries removal, as the infected dentine is taken away. Typical end values are 5–6 at the cavity floor, and 9 at the dentino-enamel junction. An appropriate threshold to use for caries removal is a DIAGNOdent score of 7 for circumpulpal dentine. Removal of caries to this point, if done using an Er:YAG laser, corresponds to the point where dentine collagen cross-links are intact, which signifies vital dentine [67].

When using fluorescence to guide Er:YAG laser caries removal, a confounding factor to avoid is deposits of beta tricalcium phosphate which can form when there is inadequate water mist spray or when the laser tip is pushed against the enamel surface during lasing. These deposits, which occur as a result of high temperature effects within enamel [68], give strong near infrared fluorescence emissions when excited by visible red light, and thus are a false positive signal that could be mistaken for infected carious dentine [69].

A final factor of importance for real time DIAGNOdent measurements of cavity preparations or tooth surfaces is quenching of fluorescence, which causes much lower readings and thus a false negative result. Applications of hydrogen peroxide and ozone can cause an immediate reduction in readings, and recovery from this takes up to 24 h [70].

2.5. 450 nm blue light for fluorescence diagnosis

In the SoproLife® intra-oral camera (Sopro-Acteon group, La Ciotat, France), visible blue light with a wavelength of 450 nm is used to excite fluorescence. Image processing enhances the green fluorescence of healthy tooth structure and the red fluorescence of dental caries.

A clinical study reported that, when using ICDAS as a reference standard, the performance of the Soprolife in terms of sensitivity and specificity for occlusal caries detection (43%) was less than that of the DIAGNOdent (62%) [71]. In a recent systematic review of the detection of occlusal caries, reported values for sensitivity for the Soporlife ranged between 43% and 95%, and for specificity between 55 and 100% [72]. Due to a limited number of clinical studies, further work is needed to confirm the validity of the SoproLife® intra-oral camera for detecting occlusal carious lesions.

2.6. Fluorescence-assisted caries excavation

The use of fluorescence to detect carious dentine remaining after cavity preparation is a technique known as fluorescence-assisted caries excavation (FACE). Teeth are illuminated with violet-blue light, and then examined using a filter which blocks the reflected excitation light, but allows longer wavelengths to pass. A 530 nm high-pass filter allows yellow, orange and red fluorescence emissions to pass. Carious dentine will fluoresce in the orange-red region. This approach is superior to conventional visual tactile (mirror and probe) examination of the cavity, and also to staining using basic fuchsin dye or acid red dye, with higher sensitivity and better specificity [73]. Caries detecting dyes do not stain bacteria in infected dentine, but rather collagen within areas where the organic matrix is altered, which means that they can also stain areas of healthy tooth structure [74–76].

To undertake FACE, the area of interest in the cavity is illuminated with 405 nm violet light, and then viewed using an orange-colored high-pass filter. The clinician can then use their instrument of choice to remove selectively all orange-red fluorescing areas. By following the FACE method, the caries excavation time is reduced, with fewer bacteria remaining in the floor of the cavity, when compared to conventional excavation, or chemo-mechanical caries removal [77, 78]. These benefits apply equally well in primary as in permanent teeth [79].

2.7. Clinical implications

Many studies have concluded that the use of fluorescence can improve the detection of carious lesions, particularly at an early stage. DIAGNOdent assessment is very useful for detection of secondary lesions, and results are highly reproducible between different examiners [80, 81]. This is an important clinical point since secondary caries is the major reason for failure of restorations. Better assessment lowers the possibility of over-diagnosis, and unnecessary repeated restoration replacement.

Because hidden deep lesions are a major challenge for traditional visual examination, it is in this area that fluorescence methods are very useful. Unlike radiographic examination, fluorescence examination is non-hazardous, and can be repeated as often as needed. In line with this conclusion, a 2013 meta-analysis of 75 studies of fluorescence-based methods for detecting caries lesions reported a trend of better performance of fluorescence methods over conventional methods for detecting more advanced carious lesions [82].

Clinical guidelines in most countries advise dentists and dental therapists who are treating children to not rely on visual examination alone, but to take radiographs to detect lesions on approximal surfaces and on occlusal surfaces that would be missed by visual inspection. In this context, fluorescence methods are an adjunct to and not a replacement for conventional methods of examination. Using fluorescence methods as adjuncts will improve sensitivity, as well as reproducibility between different clinicians [83, 84].

This then leads to discussion of what would be an appropriate or ideal sequence for clinical examination for dental caries in a manner which integrates fluorescence as an adjunctive method. Prior to the full examination, dental plaque can be shown to the patient, for the purposes of oral hygiene instruction. At this point, mature deposits of plaque can be shown using fluorescence. Calculus deposits will also fluoresce.

The next step is to remove plaque and stains, so that tooth surfaces can be examined properly. This includes flossing to remove plaque from interdental spaces.

At this point, traditional charting is undertaken using good lighting and magnification. Results from the primary visual inspection should use ICMS (ICDAS-II) or a similar system to record white spot lesions. Drying the teeth well can make these lesions more apparent, and can make pre-white spot lesions appear. Any probes used should be blunt, and only used to remove traces of debris that remain in the depths of fissures.

The next step is to use a violet-blue light fluorescence device to examine the teeth, such as an illuminator, camera, intra-oral camera or specialized dental handpiece. This examination will reveal a number of interesting features, including the true size of white spot and pre-white spot lesions because of their reduced green fluorescence. If 405 nm violet light is used, the presence of various tooth-colored restorations and fissure sealants may also become much more apparent because these do not perfectly replicate the fluorescence of natural tooth structure [85].

All restorations can now be charted. The extent of bacterial presence on incipient root lesions or open cavitated coronal lesions can be gauged by the extent of red fluorescence under violet light [86].

The next step is to use a DIAGNOdent Pen to examine pits and fissures using a conical sapphire tip. The conical tip is then replaced with the beveled tip, and an examination of the approximal enamel surfaces undertaken. A decision is then made regarding the need to use any additional special tests, such as fiber optic transillumination or bitewing radiographs, if cavitations are detected on these surfaces.

Unlike dental X-rays, fluorescence uses non-ionizing radiation and thus there are no concerns with its repeated use when it is used to monitor surfaces. The ability to better detect caries at an early stage makes it easier for the dental practitioner to apply effective remineralizing treatments to incipient enamel or root surface carious lesions, to cause caries arrest and reversal [87, 88].

2.8. Taking fluorescence diagnostic applications forward

While there are many fluorescence already in use in clinical dental practice, the technology continues to develop further. Some notable expansions of fluorescence diagnosis applications for dental caries include:

- The use of dyes to aid in detection and quantification of early demineralization [89, 90]
- The use of fluorescence ratio reference standards (FRRS) to discriminate different stages of dental caries [91].
- The use of multispectral fluorescence imaging, to distinguish between dental caries, dental calculus and fluorescence from restorative materials [92].
- The use of micro-Raman spectroscopy to provide objective evaluation of different zones within carious dentine, for minimally invasive operative caries management [93].
- The use of systems that simultaneously measure backscattering of light as well as fluorescence emissions [94].

Such technical improvements will add to the ability of dental clinicians to recognize both caries and restorations, and promote the practice of minimal intervention dentistry.

3. Conclusion

Fluorescence methods can enhance the detection and clinical management of dental caries, as an adjunct to traditional methods. Because fluorescence employs low power visible light, it can be used with safety at every dental appointment, to assess and monitor lesions. It is essential that clinicians using fluorescence methods understand the factors that affect fluorescence, and particularly the problems of false positive and false negative signals, so that appropriate measures can be put in place to address these. Correct sequencing of fluorescence inspection in the overall flow of clinical examination will remove common factors such as dental plaque that can interfere with fluorescence assessment of tooth structure. Fluorescence methods used during caries excavation can provide a useful endpoint and prevent excessive removal of tooth structure.

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Conflict of interest

The author jointly holds patents on specialized optical fibers for fluorescence diagnosis, and on couplings for dental handpieces and cameras for fluorescence diagnosis in clinical dental practice. No other conflicts of interest are declared.

Author details

Laurence J. Walsh

Address all correspondence to: l.walsh@uq.edu.au

The University of Queensland School of Dentistry, Brisbane, Australia

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Chapter 8

Can Dental Caries Be Treated?

Abeer ElEmbaby

Additional information is available at the end of the chapter

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Abstract

Realization that dental caries is a reversible, dynamic process at a micron level has changed the way the profession recognizes the caries disease. GV Black in 1908 in his text book "Operative Dentistry" advises the profession not to ignore the biological nature of dental caries. He stated that "this attitude of profession is an anomaly in science that should not continue." It has the apparent tendency to make dentists mechanics only. A goal of modern dentistry is to manage non-cavitated (demineralized) caries lesions noninvasively through remineralization in an attempt to prevent disease progression and improve esthetics, strength, and function. Remineralization can be described as mineral gain to the tooth structures. Commonly, fluoride was used to enhance remineralization. However, many side effects for its usage are confirmed. The aim of this chapter is to shed the light about several recent approaches for tooth remineralization.

Keywords: bioactive materials, biomimetic self-assembling peptide matrix, fluoride, low-level laser therapy, natural remedy

1. Introduction

Dental caries is a highly prevalent disease that is considered a major public health problem. Signs of the caries process extent from the first molecular changes in the apatite crystals of the tooth structure to a white-spot lesion, through dentin involvement and eventual cavitations [1].

Progression of dental caries requires a continual imbalance between pathological and protective factors that results in the dissolution of apatite crystals and the net loss of calcium, phosphate, and other ions from the tooth (dimineralization) [2].

The term "remineralization" has been used previously to describe mineral gain, including the precipitation of mineral onto-enamel surfaces [3]. Cochrane et al. in 2010 define remineralization as the process whereby calcium and phosphate ions are supplied from a source external to the tooth to promote ion deposition into voids in demineralized enamel to produce a net mineral gain [4].

1.1. Fluoride treatment

Fluoride has been established to enhance the rate and efficacy of remineralization. However, chronic low-level exposure to fluoride can cause some health problems (bone health problems, cancer, birth defects, and gastrointestinal tract problems) other than dental fluorosis. Therefore, it is still necessary to seek alternative, effective non-fluoride agents that can provide a complete cure for caries.

The action of fluoride in remineralization is the gold standard to which newer therapies are compared. The requirements of an ideal remineralization material are as follows. It must diffuse into the subsurface or deliver calcium and phosphate into the subsurface lesion [5, 6].

There are several recent approaches for remineralization:

- laser-activated fluoride (LAF)
- low-level laser therapy (LLLT)
- bioactive materials

  Recaldent

  NovaMin

  tri-calcium phosphate

  biodentine tri-calcium silicate cement

  nano-hydroxyapatite
- Biomimetic self-assembling peptide matrix

  curodont repair

  icon
- Natural remedy

1.2. Laser-activated fluoride

Laser-activated fluoride (LAF) is a method to combine laser irradiation and topical fluoride application in one technique by which the resistance of the enamel to demineralization is increased. Laser irradiation has been found to reduce the critical pH of dissolution of hydroxyapatite crystals from 5.5 to 4.3. In the presence of fluoride, further reduction has been revealed [7].

1.3. Low-level laser therapy

While most applications of low-level laser therapy (LLLT) in dentistry are directed toward soft tissues, in recent times, there has been increasing interest in tooth-related or hard-tissue

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applications of LLLT. There is accumulating evidence which indicates the potential of low-level laser therapy as a technique for the destruction of cariogenic bacteria without causing undue thermal stress to the tooth as well as increasing the enamel's acid resistance better than those of fluoride treatment. LLLT was shown to be efficient in the stimulation of odontoblast cells, producing reparative dentin and sealing dentinal tubules [8].

2. Bioactive remineralizing materials

2.1. Stabilized amorphous calcium phosphate systems

It combines casein phosphoproteins from milk with amorphous calcium phosphate (CPP-ACP). Amorphous calcium phosphate (ACP) induces a thin surface coating of hydroxyapatite when applied topically. This is a surface phenomenon that is basically different from the remineralization of enamel subsurface lesions which require the actual penetration of ions into enamel.

The bioavailable complexes of casein, calcium, and phosphate are created in the appropriate form for optimal remineralization of subsurface lesions in enamel, not just on the surface, for example, Recaldent is available in solutions, gums, lozenges, and creams [9].

2.2. Crystalline calcium phosphate remineralizing systems

NovaMin is technically described as an inorganic amorphous calcium sodium phosphosilicate (CSPS). It belongs to a class of materials which are known as "bioactive glasses."

Preceding the invention of bioactive glass, all biomaterials were designed to be as inert as possible in the human body. The discovery that a synthetic biomaterial could form a chemical bond with bone proved that biomaterials could be engineered to be active with the body. Bioactive glasses enable hydroxyapatite deposition when exposed to fluids containing calcium and phosphate.

Many studies have shown NovaMin particles to act as reservoirs and continuously release calcium and phosphate ions into the local environment. The calcium-phosphate complexes crystallize into hydroxycarbonate apatite, which is chemically and structurally like biological apatite. NovaMin has been incorporated into toothpastes, gels, and prophy pastes.

A novel delivery system for NovaMin is through an air-polishing unit. NovaMin powder also has positive remineralization effects on partially and completely demineralized models of dentin [10].

2.3. Crystalline calcium phosphate remineralizing systems

Tri-calcium phosphate (TCP) is a bioactive and simple organic ingredient. It works synergistically with fluoride to produce superior remineralization of enamel subsurface lesions when compared to using fluoride alone. A protective barrier is created around the calcium, allowing it to coexist with the fluoride ions. When it comes in contact with saliva, it causes the barrier to dissolve and releases calcium, phosphate, and fluoride. Studies are currently underway to demonstrate the clinical advantages of TCP. The above remineralization therapies work directly to enhance the concentration of calcium, phosphate, and fluoride [11].

2.4. Biodentine tri-calcium silicate cement

Biodentine is a new bioactive calcium silicate-based product that has been designed as dentin replacement material. It can be used in endodontic repair (root perforations, apexification, and resorptive lesions), pulp capping, as well as dentin replacement in restorative dentistry. It was formulated by taking the MTA-based technology, improving its physical and handling properties and creating a dentin replacement material with significant reparative qualities.

Biodentine penetrates the dentinal tubules forming tag-like structures that produce a micromechanical lock with the tooth. It then begins to stimulate reparative dentin. Biodentine has been revealed to enhance the formation of reparatory dentin and to create a dense dentin barrier after direct pulp capping as well as healing damaged pulp fibroblasts [12].

2.5. Nano-hydroxyapatite

Nano-hydroxyapatite (nano-HA) is one of the most biocompatible and bioactive materials and is widely applied to coat artificial joints and tooth roots. Due to the similarity to the tooth apatite in chemical composition and crystal structure, hydroxyapatite nanoparticle (nano-HA) is reported to have the potential to repair demineralized enamel lesions.

Naturally, many nano-blocks combine into self-assembled biominerals under the control of an organic matrix. Nonetheless, whether the remineralization effect of nano-HA on dentin would be better in the presence of organic component is still indistinct [13, 14].

2.6. Self-assembling peptides (enamel regeneration)

Enamel regeneration with self-assembling peptides enables a completely new treatment option for initial caries. It mimics the enamel matrix and the initiation of tooth regeneration via biomineralization. Reversal of the caries progresses toward remineralization by a three-dimensional regeneration of early enamel lesions, avoiding subsequent invasive caries treatments.

During odontogenesis, the three-dimensional amelogenin matrix enables crystallization and ordered calcium phosphate crystal growth. The matrix is subsequently degraded. Scientists from the University of Leeds found a way to mimic the enamel matrix within enamel lesions by self-assembling peptides matrix and thus enabling enamel regeneration, marketed as Curodont 2013.

Self-assembling peptides are widely used in tissue engineering and to produce three-dimensional cell cultures. Self-assembling peptides form spontaneously a biocompatible three-dimensional matrix that mimics the enamel matrix. Around the newly formed matrix, calcium phosphate from saliva crystallizes, forming new enamel. The process uses the natural remineralization process that is in a healthy tooth.

When Curodont repair is applied onto a carious lesion, the monomers diffuse through the pores into the subsurface lesions. In the subsurface cavities, they form the three-dimensional matrix around which the crystallization of calcium phosphate occurs.

This process is comparable to the mineralization process that occurs during odontogenesis, or the remineralization process which is in equilibrium with the demineralization process. Curodont repair arrests initial caries and initiates the natural, three-dimensional regeneration of enamel, the tooth heals [15, 16].

2.7. Peptide-based infiltrate

The technique uses a peptide-based fluid (e.g., Icon) which is painted onto the tooth's surface to infiltrate inside the pores of the demineralized enamel to fill the spaces and enhance remineralization. It enables immediate treatment of lesions not yet advanced enough for restoration. It arrests caries progress without unnecessary loss of healthy tooth structure and cosmetic treatment of cariogenic white lesion. No drilling or anesthesia is required [17].

2.8. Natural remedy for dental caries

There is a great trend nowadays to use natural materials as cure for many diseases. Alternative medicine has made a lot of contributions to modern medical practice.

Dental plaque plays an essential role in the pathogenesis of dental caries. The occurrence of dental bacteria depends on the bacteria coherence, acidogenicity, and acid resistance. Control of the oral biofilm includes removal or reducing the biofilm mass or acidogenicity through mechanical and/or chemical interventions. Previously, chemical synthetic agents such as chlorhexidine gluconate and tri-closan have demonstrated their efficiency as antibiofilm agents [18, 19].

However, the excessive use of synthetic agents leads to side effects including alteration of the oral cavity environment and the bacterial tolerance. A natural anti-plaque agent with safe efficacy and potent activity may be attractive for daily oral care.

2.8.1. Green tea

Many reports in experimental animals and humans suggested that green tea consumption (without added sugar) reduces dental caries as it acts as an antibacterial agent.

In addition, green tea decoctions inhibit α-amylase in human saliva, reducing maltose release by 70% and effectively lowering the cariogenic potential of starch-containing food. Apart from their polyphenol content, both green and black tea are a natural source of fluoride as well as an effective vehicle for its delivery in the oral cavity. Many studies revealed that by using tea as a mouthwash, approximately 34% of the fluoride is retained and shows a strong binding ability to interact with the oral tissues and their surface integuments [20, 21].

2.8.2. Propolis resinous mixture

Propolis is a nontoxic natural substance collected by *Apismellifera bees from various plant sources and has been used* in folk medicine for centuries. It is known that propolis exhibits several biological activities, such as antimicrobial, anti-inflammatory, anesthetic, cytostatic, antitumor, hepatoprotective, antioxidant, hematostimulative, immunomodulatory, and cariostatic properties.

The chemical composition of propolis is complex; flavonoids and (hydroxyl) cinnamic acid derivatives have been considered the primary biologically active compounds. Propolis has also been used in dentistry for surgical wound healing, root canal treatment, pulp capping, and tooth hypersensitivity. Different commercial propolis products are available in market. Propolis has a promising role in future medicine [22].

Dental caries was markedly decreased by the multiple actions of propolis which had an antimicrobial activity against *S. sobrinus*, *S. mutans,* and *S. cricetus*, inhibited water-insoluble glucan synthesis, and inhibited glucosyltransferase activity.

Propolis has a wide range of biological activities; the potential of propolis and its compounds as cariostatic agents is a thought-provoking contribution to develop bioactive products to control caries activity. Therefore, guidelines for quality control should be implemented since the high variability in the chemical composition of propolis is an important obstacle to be overcome before it can be recommended for routine application in dentistry clinics [23].

2.8.3. Coconut oil

Coconut oil has received much attention of late; coconut oil is the richest sources of saturated fat. Most of these fatty acids are medium-chain triglycerides.

They are metabolized differently than the long-chain fatty acids found in most other foods and have many potential health benefits.

A medium-chain fatty acid (lauric acid) makes up almost 50% of coconut oil. This oil breaks down into a compound called monolaurin. Both lauric acid and monolaurin can kill harmful bacteria, fungi, and viruses in the body [24]. According to research, many of the health benefits associated with coconut oil are directly caused by lauric acid [25].

Lauric acid is particularly effective against harmful bacteria in the mouth that can cause bad breath, dental caries, and gum disease [26].

The most popular ways to use coconut oil for your teeth are using it in a process called “oil pulling,” or making toothpaste. Oil pulling is the act of using oil as a mouthwash for 15–20 min and then spitting it out.

Coconut oil has an antibacterial effect against *Streptococcus mutans* and *Lactobacillus*, which are the primary bacteria responsible for dental caries [27].

Several studies suggest that coconut oil can be compared to chlorhexidine which is the active ingredient used in many mouth rinses in reducing these cariogenic bacteria [28–31].

For these reasons, coconut oil can help prevent plaque formation and dental caries.

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2.8.4. Turmeric (haldi)

Turmeric is a flavorful yellow-orange spice. Turmeric has been attributed for several medicinal properties in the traditional medicine. Components of turmeric include mainly curcumin (diferuloylmethane), demethoxycurcumin, and bisdemethoxycurcumin. The active constituents of turmeric are the flavonoid curcumin (diferuloylmethane) and various volatile oils including tumerone, atlantone, and zingiberone. Other constituents include sugars, proteins, and resins. Curcumin has been used extensively in medicine for centuries, as it is nontoxic, antioxidant, analgesic, anti-inflammatory, antiseptic activity, and anticarcinogenic activity [32].

Many researches were performed to compare the effect of turmeric mouthwash to that of standard treatment—chlorhexidine gluconate mouthwash in treating gingivitis and plaque. A significant reduction in plaque index and microbial count was observed with turmeric mouthwash. However, chlorhexidine gluconate mouthwash was more effective when antiplaque property was considered [33].

2.8.5. Licorice root

The main active ingredient in licorice root is glycyrrhizin. However, over 600 active components have been identified in the plant, including 10 bioflavonoids which act to strengthen the immune system [34].

Two antibacterial ingredients were extracted from licorice root: licoricidin and licorisoflavan A. In 2012, an international published research by the American Chemical Society linked these chemicals to oral health.

The researchers found that each chemical strongly inhibited two major cariogenic bacteria—*S. mutans*, which is the most important bacterium, induces dental caries, and *S. sobrinus*. The chemicals also had a major inhibitory effect on two common gum disease bacteria: *Porphyromonas gingivalis* and *Prevotellaintermedia*. In addition, the licoricidin moderately inhibited a third bacterium, *Fusobacterium nucleatum*, which is often associated with periodontal disease [35].

2.8.6. Miswak Alvadora Persica

Miswak has been used as a natural toothbrush for centuries. The World Health Organization has also promoted its use for oral hygiene. Many researches revealed that Miswak can prevent dental caries, bad breath, and it can be used in toothache [36].

Miswak contains the following compounds: lauric, myristic, and palmitic acids; polysaccharide and lignin derivatives of phenols and furans; sterols. The benzylisothiocyanate isolated from the Meswak showed an antiviral activity and acts as an agent for controlling dental caries, even when used without any other tooth-cleaning methods. The use of Meswak extract chewing gum may promote a decrease in plaque, bleeding, and gingival indices. The tannins and resins in Meswak have an astringent effect on the mucus membrane and form a layer over the enamel which indeed gives protection to the teeth [37, 38].

Silica in Miswak acts as an abrasive material to remove plaque and stains. Tannins present in Miswak exert an astringent effect on the oral mucous membrane, thus reducing gingivitis and other dental pathologies [39].

2.8.7. Gallachinensis

Gallachinensis has been widely used as a natural traditional Chinese medicine. Gallachinensis exhibits antibacterial, antiviral, antioxidant, hepatoprotective, antidiabetic, antithrombin, antidiarrheal, anti-inflammatory, antitumor activity, and detoxification properties [40–42].

Gallachinensis extract contains significant quantities of monomeric and polymeric polyphenols (gallotannin and gallic acid), carbohydrates, and proteins. Gallotannins was found to be bactericidal for cariogenic bacteria [43–47].

Extracts from gallachinensis (Ellagic acid) has been proposed to reduce the glucan-mediated adhesion of *S. mutans* to saliva-coated hydroxyapatite. The bioactivity of gallachinensis extract is a result of synergistic effects and/or antagonistic effects of several compounds [48, 49].

Previous studies revealed that gallachinensis has anticariogenic and outstanding effects in promoting hard-tissue remineralization [50, 51].

3. Concluding remarks

A goal of modern dentistry is the noninvasive management of non-cavitated caries lesions involving remineralization systems to repair the enamel. In individuals at risk of disease, procedures should be instituted to prevent the onset of disease, and those in whom disease is already evident, the lesions should be treated noninvasively by remineralization.

Interest in the discovery of natural, safe, and novel anti-infective compounds derived from plants is ongoing in the scientific community.

Author details

Abeer ElEmbaby[1,2]

Address all correspondence to: aeelembaby@uod.edu.sa

1 Restorative Dental Sciences Department, College of Dentistry, University of Dammam, Saudi Arabia

2 College of Dentistry, Mansoura University, Egypt

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Chapter 9

Management of White Spot Lesions

Ceren Deveci, Çağdaş Çınar and Resmiye Ebru Tirali

Additional information is available at the end of the chapter

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Abstract

It has been reported that white spot lesions (WSLs) can be seen as a result of prolonged plaque accumulation on the affected surface of the teeth. They are more often associated with fixed orthodontic treatment and defined as "the presence of clinically detectable, localized areas of enamel demineralization." These lesions are managed in the first step by establishing a good oral hygiene to enhance remineralization, and prophylaxis with products mostly containing fluoride, calcium, or phosphate. The aim of this chapter is to outline the risk factors and preventive measures of WSLs, and the currently used methods to manage it based on the latest evidence.

Keywords: white spot lesions, etiology, diagnosis, remineralization, fluoride

1. Introduction

White spot lesions (WSLs), defined as "white opacity," occur as a result of subsurface enamel demineralization that is located on smooth surfaces of teeth [1].

The reason of the white appearance is the changes in light-scattering optical properties of the decalcified enamel [2]. Various risk factors such as acid-producing bacteria, fermentable carbohydrates, and many host factors, such as poor oral hygiene, low salivary volume, and a sugary diet, further the development of these incipient lesions [3].

A review of the literature has shown that WSLs develop as a result of prolonged "undisturbed" plaque accumulation on the affected teeth surface, commonly due to inadequate oral hygiene [4–9]. Under these conditions, acids diffuse into the enamel and the demineralization continues in the subsurface enamel, then the intact enamel surface collapses and becomes cavitated [10]. It has been shown that these lesions can appear within 4 weeks [11].

The concept of caries process was explained with a model; it was initiated by fluctuations in pH caused by the bacteria that are always metabolically active in the biofilm or dental plaque. These fluctuations may cause erratic loss and gain of mineral ("demineralization" and "remineralization") [12]. As a total result of these continuous demineralization and remineralization processes of enamel that occur episodically based on the presence of cariogenic bacteria in dental plaque and the availability of refined carbohydrates for fermentation to organic acids [13], dissolution of the dental hard tissues develops and a caries lesion forms [14].

In the first stage of the enamel defect there is a lower mineral distribution and also a lower interprismatic mineral content in the surface layer [15]. It has been proposed that further dissolution of the outer 10–30 microns of enamel is prevented relatively by several metabolic formations. The protective roles of salivary proline-rich proteins and other salivary inhibitors like statherin have also been emphasized [16]. But they cannot penetrate the deeper parts of the enamel due to their macromolecule structures; so their stabilizing role is limited for the surface enamel [17]. The white-spot lesion's shape is determined by the distribution pattern of the biofilm and the direction of the enamel prisms [18].

The presence of fixed orthodontic appliances causes an increasing number of plue retention sites as a result of the presence of brackets, bands, wires, and other applications, which makes the cleaning of teeth more difficult [4, 5, 7, 9, 10, 19–22].

When the orthodontic bands are removed and the feasibility of tooth cleaning is provided, it results a reduced porosity of the deeper parts of lesions (**Figure 1**). The return of fluids to supersaturation condition causes a shift in equilibrium and reprecipitation of minerals at the sites of demineralization. As a result of this, the surface of the lesion may become hard and shiny, and then the white spot becomes less obvious, but some interior opacity remains [23].

It is important to understand how these lesions develop and what the risk factors are. Because it is a great challenge to make an early detection of WSL that would allow clinicians to apply preventive measures to control the demineralization process before lesions progress.

The aim of this chapter is to outline the risk factors and preventive measures of WSLs, and the currently used methods to manage them based on the latest evidence.

Figure 1. White spot lesions after completion of fixed appliance orthodontic treatment.

2. Prevalence

The prevalence of WSLs varies widely in the literature. It ranges from 23 to 95% when different evaluation methods and criteria are used [5, 20, 24–28].

Mizrahi [29] examined 527 patients before and 269 patients after fixed appliance orthodontic treatment to search the prevalence and severity of enamel opacities in a cross-sectional study. The results showed that both the prevalence (72.3–84%) and the severity (opacity index, 0.125–0.200) increased with the treatment. The study also concluded that there was a significant difference between male and female patients. Male patients experienced greater increases in the severity of enamel opacities than females did. However, there was no significant sex differential in the prevalence of enamel opacities either before or after the orthodontic treatment. Similar results about gender were obtained in another recent study [24]. This study also concluded that 23% of the patients developed WSLs during fixed appliance orthodontic treatment, and WSLs developed more frequently in the maxillary arch than they did in the mandibular. The researchers identified other risk factors during the treatment such as treatment time exceeded 36 months, patients with poor oral hygiene, and patients whose oral hygiene declined during treatment and pre-existing WSLs. They observed that the lesions are often symmetrical and occurred more frequently on the maxillary laterals, maxillary canines, and mandibular canines. In other studies, different results were obtained. According to these studies, the most inclined teeth to demineralization are the first permanent molars, the maxillary incisors, the mandibular lateral incisors, and canines [2, 26, 30].

Boersma et al. [31] examined caries lesions on the buccal surfaces of teeth in orthodontic patients by using quantitative light fluoroscopy versus visual examination immediately after removal of fixed appliances and concluded that 97% of the subjects had one or more lesions, and on average, 30% of the buccal surfaces in a person were affected and also highlighted that mutans streptococci counts, age, duration of treatment, socioeconomic status, and dietary habits showed no correlation with caries prevalence.

Results of a recent meta-analysis have demonstrated that in the 14 studies evaluated for WSLs, the occurrence of WSLs is common during fixed orthodontic treatment with an incidence and prevalence rate of 45.8 and 68.4%. It has been proposed that the risk of developing WSLs during orthodontic treatment should not be underestimated by orthodontists, necessitating the search for further methods to counter the risk of development of these lesions [32].

The reported prevalence of WSLs is quite variable, depending on the sample size, method of detection, the use of a fluoride regimen during treatment, inclusion of pre-existing developmental enamel defects, and selected patients groups [30].

3. Etiology

Dental caries is a community disease that develops due to biological factors that are present within the saliva and dental plaque and is closely related to the type and frequency of carbohydrate ingestion, as well as the oral hygiene practiced by the individual. The protective factors also presented as salivary flow rate, buffering capacity, antimicrobial activity, microorganism aggregation, and clearance from the oral cavity, immune surveillance, and calcium phosphate binding proteins all interact to inhibit or reverse demineralization of exposed tooth surfaces [13].

As previously explained, the WSLs can occur on any tooth surface in the oral cavity, where prolonged "undisturbed" plaque accumulation exist; in other words, the surfaces that microbial biofilm forms on exist. The other important factors that impact this process are the patient's modifying factors, including medical history, dental history, medication history, diet, levels of calcium, phosphate, and bicarbonate in saliva, fluoride levels, and genetic susceptibility [33].

No change was seen clinically on the enamel after 1 week in the presence of undisturbed biofilm even after samples had been carefully air-dried. The outer surfaces of the enamel showed dissolution from the crystal's peripheries, and inter-crystalline spaces enlarge. Two weeks later, the changes in WSLs become visible after air-dried. After 4 weeks, the lesions could be seen without air-drying and as opaque on a matte surface [34].

Orthodontic treatment has been reported as the most frequent factor for this situation, and equal susceptibility has been reported whether teeth are banded or bonded [2, 4, 5, 7, 9, 10, 19–22, 35, 36].

Tufekci et al. [5] demonstrated a sharp increase in the number of WSLs during the first 6 months of treatment and it continued to increase at a slower rate up to 12 months in a clinical study. They suggested evaluating the oral hygiene status of patients during the initial months of treatment and, if necessary, implementing extra measures to prevent demineralization.

Fixed orthodontic appliances cause inaccessible areas for plaque and make tooth cleaning difficult. The oral musculature and saliva cannot clean tooth surfaces caused by the limitation of irregular surfaces of brackets, bands, and wires [33], furthermore, excess bonding, long etching time (>15 s), decayed/treated molars, and the duration of treatment are considered other risk factors [26, 37]. The colonization of aciduric bacteria encourages biofilm formation resulting in a rise in the levels of mutans streptococci and lactobacilli [38, 39]; in time, this causes active WSLs, and, if not treated, a cavitated caries lesion can develop.

Demineralization areas without cavitation are colonized by mutans streptococci (11–18% of total streptococcal count) in about 12–18 months prior to becoming clinically visible. In the remineralization process, mutans streptococci are reduced substantially (2–5% of total streptococcal count) [40, 41].

The critical pH for dissolution of dental hydroxyapatite is 5.5, but mutans streptococci and lactobacilli have pH of 3.9–4.1, which is well below it. Dental plaque buffering capacity and degree of calcium and phosphate supersaturation will determine the demineralization process [42–48].

The goal of modern dentistry is to determine all the risk factors and preventive measures by understanding all mechanisms responsible for demineralization leading to WSLs in order to intervene non-invasively and improve the strength, esthetics, and functions of teeth.

4. Diagnosis of white spot lesions

WSLs are opaque, white, and soft lesions characterized by demineralization on the tooth surface [36, 49]. The early diagnosis and treatment of these lesions, which are difficult to diagnose because of their characterization by submerged enamel demineralization, can prevent tooth decay and clinical caries formation.

Many tools can be used to diagnose WSLs including traditional visual inspection, mirror-sound applications and radiographies, trans-illumination methods, fluorescence methods, electrical conductivity, ultrasonic methods, and other newly developed technologies.

4.1. Visual inspection and radiography

The simplest method of detecting WSLs is the mirror-sound application and visual inspection. The demineralization of the enamel and microporosity affects the transmission of light within the enamel. Thus, the enamel layer loses its bright color and appears opaque-white due to optical refraction. Using a standard examination light and mirrors, opaque white lesions can be detected through the clinician's visual examination. These lesions are often seen as opaque, matt, or chalky white areas around the labial cervical third and under orthodontic brackets, where bacterial plaques accumulate, they vary in size and are not clearly distinguishable. The surface of the enamel is protected, but roughness and micro-ridges (perikymata) are visible on the surface. In addition, it is possible to detect small defects using small rounded probes. The use of spiked probes is not recommended because it can cause defects in the softened enamel [50]. Yassin [51] showed that with micro radiological methods in an *in vitro* study, the use of spiked probes in a robust demineralized enamel model can cause cavitation in WSLs.

The addition of conventional radiographs to visual examination increases the diagnostic probability. However, ionized radiation exposure is the most obvious disadvantage. Other possible disadvantages are cases, where the outermost layer of enamel is intact and cases, where occlusal lesions without macroscopic deterioration are hard to diagnose. There is a lack of radiographic examination in more than 40% of approximal caries of enamel [52]. Previous studies showed no difference in diagnostic efficacy between conventional and digital bitewing radiographs [53].

With computer aided diagnosis, a computer program, we can interpret the radiographs to distinguish between robust, demineralized, and caries teeth. The Logicon System (Carestream Dental LLC, Atlanta, GA) is an example of this technology. The program matches the radiographs with clinical images, compares them, and provides a dental density chart in graphical format [54].

4.2. Trans-illumination methods

The rapid development of imaging technology is beginning to help in the early detection of caries development. Fiber optic trans-illumination (FOTI) and digital imaging fiber optic trans-illumination (DIFOTI), where light transmission is used, are among the methods. The use of fiber optic light makes it possible to see smaller superficial white lesions; it undergoes optical refraction by passing an intense light beam through the tooth. In the DIFOTI method, focused images can be taken with the help of a CCD camera installed in the system. The images can be analyzed by a computer and the diagnosis of approximal, occlusal, and soft surface caries can be done simultaneously. It allows documentation of the lesion and follow-up of the progression [55]. The DIFOTI method can detect demineralization as early as 2 weeks, but DIFOTI fails to measure the depth of the lesion [56].

4.3. Florescence methods

There are also systems that use the natural fluorescence that occurs in tooth enamel. The light emission coefficient of a caries lesion is higher than healthy enamel resulting in lower fluorescence in caries lesions [57]. Quantitative light measuring fluorescence (QLF) is associated with light changes in the natural fluorescence of hard tissue. The 50-W-xenon light, produced by the QLF hand tool, passes through the blue filter and reaches the tooth. The fluorescence light emitted from the tooth is collected by a camera mirror, passes through a yellow filter that eliminates light below 520 nm, and is sent to a computer program for examination. With QLF, the tooth is exposed to blue light, which stimulates green fluorescence from the hard tissues. In demineralized foci, a decrease is detected in this natural fluorescence and is seen as darker areas. Red fluorescence is seen due to porphyrins metabolized by bacteria in tartar, plaque, or infected caries lesions. Computer-aided QLF methods can also be used to evaluate the progression of the lesion and treatment response [58, 59]. The QLF system has high interobserver consistency and is effective at preventing false negatives [59].

Another method that uses the florescence characteristic of teeth is laser fluorescence (DIAGNOdent—KaVo, Germany). The fluorescence of the laser beam is less in demineralized enamel than normal enamel. With the method developed by Lussi in 2004, a red diode laser beam of 650 nm is applied to the occlusal surface of the tooth. It is collected using an optical fiber located at the same end, filtered by high frequency light wavelengths, and counted by a photodiode. Only low-frequency fluorescence that passes through the caries lesion is measured and quantified. Thus, the name "quantifiable laser fluorescence" is used as a value of the measurement scale, and when it increases, the likelihood of decay increases. A value of 5–25 indicates early lesions, 26–35 indicates early dentin caries, and over 35 indicates deep dentin caries. The most important disadvantage of this system is that it can give false positive results in the presence of painted fissures, plaque and calculus, pit and fissures sealant, and in the presence of restorative material [57, 60]. Therefore, it is important to clean the tooth surface when using DIAGNOdent. A study by Pretty [59] showed that laser fluorescence technology has higher specificity compared to electrical resistance, FOTI, and QLF. Although it has the advantages of allowing very early caries detection, reproducibility, and measurement on approximal, buccal, and lingual surfaces with different tips without any destruction, it has the disadvantages of being expensive and having the sensitivity to give false positive results. Çınar et al. [61] compared the DIAGNOdent and DIAGNOdent pen with visual examination and bitewing radiographs for detection of occlusal caries. They found that for outer enamel lesions DIAGNOdent pen has higher sensitivity than radiographs.

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4.4. Electrical conductivity

Difference arises in the electrical transmission of solid and demineralized enamel surfaces due to porosity. Saliva penetrates the enamel and increases the electrical permeability of the tooth [62]. This electrical conduction is measured by a connector placed on a region with high conductivity such as the gingiva or skin and a probe placed into the fissure.

Today, the most important device used for this purpose is the electronic caries monitor (ECM) (LODE Diagnostic, Groningen, The Netherlands). The ECM has a limited capacity on the occlusal surface in general. It is more successful on smooth and approximal surfaces. Compared with clinical visual methods, the sensitivity of this system is higher but the specificity is lower [63].

Another method based on electrical conductivity measurement is alternating current impedance spectroscopy (CarieScan). In this method, multiple electrical frequencies are used to detect occlusal and soft surface caries. A surface of the tooth is isolated by drying with compressed air and the suspicious area is examined. If the entire surface is to be examined, an electrolyte solution is used and the probe tip is placed in a larger area. This method, which is unaffected by dyes and discoloration, is more accurate and reliable than the ECM [64].

4.5. Ultrasonic methods

The high frequency sound waves applied by the probe are converted back to electrical impulses as they return from the textures and the echo (reflection) they form is detected. Ng et al. [65] reported that high-frequency pulse-echo ultrasound waves (18 MHz) produce different echoes in robust and demineralized enamel.

Studies have shown that ultrasound is a successful method in deep dentin lesions, but it is even more useful in evaluating remineralization. A study comparing ultrasound against radiography and histology in mandible molar teeth for detection of WSLs reported the sensitivity and specifity of the method as 88 and 86%, respectively. It was concluded that ultrasound was a useful tool for detection of these lesions [66].

4.6. Optical coherence tomography and polarization sensitive optical coherence tomography

Optical coherence tomography (OCT) uses infrared light to obtain high-resolution images of approximately 10–20 microns with confocal microscopy and low coherence interferometry. The accuracy of OCT is quite high and it can show early mineral changes in the *in vivo* environment with exposure to acid for only 24 h using near infrared reflectivity. Polarization sensitive OCT (PSOCT) has also been used to study the spatially resolved scattering and polarization phenomena of teeth, which are known to have a strong polarization effect [67, 68].

4.7. Frequency-domain laser-induced infrared photothermal radiometry and modulated luminescence

Frequency-domain laser-induced infrared photothermal radiometry and modulated luminescence technology (PTR/LUM) is based on the principle that infrared laser light absorption of the tooth is measured depending on the resulting temperature change (exchange interval of less than 1°). In this method used by Canary System (Quantum Dental Technologies), the thermal energy conversion of the optical energy provides better evaluation of tissue density and lesion depth than visual techniques [62]. In another laboratory study, it was stated that radiography is more sensitive than visual or laser fluorescence technology [69].

5. Differential diagnosis of white spot lesions

WSLs occur due to hypomineralization of the enamel. Conditions causing hypomineralization such as fluorosis, traumatic hypomineralization, molar-incisor hypomineralization, genetic defects causing enamel hypoplasia, as well as environmental factors should be considered during the diagnosis. WSLs appear translucent when the surface is moist, and opaque-white when the surface is dried with air spray. Other hypomineralized lesions are often opaque-white when the surface is moist. The surface of WSLs is softer and rougher, and dental plaque accumulation is often observed in these areas.

Fluorosis is a hypomineralization that occurs as a result of excessive incorporation of fluorides during the formation of enamel. Excessive fluoride uptake and the use of fluoride-containing substances occur after symmetrical interaction of the homologous teeth and influence different tooth groups. In the early phase, convergent horizontal white lines cause a parchment-like appearance accompanied by irregular chalky areas. Histopathologically, hypermineralization occurs in the superficial layer of teeth with dental fluorosis and hypomineralization occurs in the subsurface of the external third of enamel. Then, a brown color change occurs due to the infiltration of exogenous chromophoric proteins [70].

Traumatic hypomineralization occurs as a consequence of periodontal trauma affecting deciduous teeth. The severity of the trauma is not related to the level of hypomineralization. Even a simple, unobtrusive shock can cause the formation of these defects [70]. Periapical inflammation after trauma affects germ mineralization. Traumatic hypomineralization can occur in many different shapes, borders, localizations, and colors. They often occur as punctiform lesions in the dental crowns of the incisal third. They usually affect one tooth asymmetrically with respect to the corresponding contralateral teeth. Although the trauma story gives an idea for the diagnosis of these lesions, it is sometimes difficult to remember simple shocks, so the diagnosis of these lesions is often made by excluding other causes [71].

Molar incisor hypomineralization is the least known lesion in differential diagnosis. In the clinic, at least one of the four most permanent molar teeth must have a qualitative enamel defect. Permanent incisors can also be affected. Sometimes the cusps and second molars can also be affected. It is important that the molars and permanent incisors have well-defined white, yellow, or brown opacities on the occlusal surface of the crown. Enamel splints are present and they modify the occlusal anatomy of the first molar teeth. Excessive tooth sensitivity and anesthesia difficulties secondary to underlying pulpal inflammation occur. The shapes and edges of restorations are atypical and early failures of restorations can be seen. It should be considered in unexplainable extractions of the first molars in patients without

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caries. Respiratory diseases causing hypoxia, episodes of recurrent febrile infections, and exposure to dioxin should be questioned [69, 72].

Genetic factors causing enamel hypoplasia and hypomineralization include Amelogenesis Imperfecta, Congenital Erythropoietic Porphyria, Ectodermal Dysplasia, Epidermolysis Bullosa, Tricho-dento-osseous Syndrome and syndromes causing Hypoparathyroidism (Velocardiofacial Syndrome, DiGeorge Syndrome, 22q11.2 deletion syndrome, Kenny-Caffey Syndrome). Smoking habits of the mother, low birth weight, Celiac disease, and Vitamin D deficiencies like Rickets can also cause hypomineralization. Infections such as Congenital Syphilis, Chicken Pox, Rubella, Measles, Mumps, and Cytomegalovirus can cause enamel defects. Apart from fluoride, tetracycline and cytotoxic drugs, lead intoxication, and Pica ingestion can lead to discoloration, and enamel defects in teeth [70].

6. Management of white spot lesions

6.1. Oral hygiene

The aim of modern dentistry is to manage initial caries lesions non-invasively through remineralization to prevent disease progression [73]. Oral hygiene is very important in protecting teeth against WSLs. This can be firstly achieved by both motivation and education of patients [74].

It is well known that tooth brushing, which is an effective way to remove plague/biofilm from the tooth surfaces prevents oral diseases such as caries, gingivitis, and periodontitis to a significant extent. Therefore; today, it is a standard to use a toothbrush as a personal daily oral hygiene procedure in developed countries.

Mechanical cleaning is provided by brushing teeth with fluoride containing toothpaste and flossing [74]. The effective removal of plaque from the tooth surface by proper brushing is well known to prevent dental caries [75]. The technique and frequency vary according to the patient's disease pattern and oral hygiene needs [76]. Kuhnisch et al. [77] recommended that twice-daily removal of the dental biofilm by brushing teeth with fluoride toothpaste prevent new caries lesions.

Although manual brushing of teeth is a very simple and effective method, a number of studies have stated that the time and effectiveness of tooth brushing are inadequate. Most children brush their teeth regularly, but for only 30–45 s. Depending on their age and manual skills, teeth may be insufficiently cleaned [78, 79]. While the timer of the power toothbrushes makes sure that children spend adequate time brushing their teeth, the inherent bristle movement may make up for their limited dexterity particularly in cleaning hard-to-reach areas like interproximal tooth surfaces [80].

6.2. Fluoride

The initial stage of WSLs can be treated successfully with good oral hygiene, topical fluoride application, and/or other caries-remineralizing agent [81]. Ideal remineralization material should be bioavailable in order to diffuse or deliver calcium phosphate into the lesion or boost the remineralization properties of saliva and oral reservoirs, without calculus formation [73, 82].

Topical fluoride application is the first choice of many clinicians to treat WSLs. During topical fluoride application, a calcium fluoride-like material (CaF_2) develops in plaque, on the tooth surface or initial caries lesion. When the pH value decreases during a caries attack, $CaF_2$is used as a reservoir of fluoride ions for release [2, 83]. Also when there is fluoride on the enamel surface, fluoroapatite, which has a more durable structure than hydroxyapatite, is formed [36]. This is believed to be a major mechanism of fluoride action in enamel remineralization [84–86]. In addition, topical fluoride application increases plaque pH and inhibits bacterial metabolic pathways indirectly, thus enamel demineralization reduces and remineralization enhances [87].

Low-dose topical fluoride is recommended over long periods of time with frequent exposures in order to avoid dental fluorosis [87, 88].

High concentration applications of fluoride to WSLs are usually preferred in clinical practices; however, highly concentrated fluoride leads to hypermineralization of surface layer of WSLs. Therefore, the penetration of calcium and phosphate ions into the body of lesion is blocked. This is referred to as lamination. It may have some undesirable esthetic consequences [36, 89].

A slow calcium, phosphate, and fluoride ion penetration from saliva or low concentrations of fluorides should be allowed to the WSLs firstly. In this way, more esthetically agreeable results will be achieved. This kind of treatment regimen may remineralize the mild WSLs from the deeper parts of the lesion to the outer surface layers of the enamel. Therefore, the chance to get a successful and more esthetic treatment result increases [36].

Remineralization with saliva is small and slow process. There is a tendency for the mineral gain to be in the surface layer of the lesion because low ion concentration gradient occurs from saliva into the lesion [73].

Frequent exposure to low levels of fluoride is the most important part of the prevention and remineralization of caries. This can be achieved by using fluoride toothpaste, mouthrinses with fluoride, and fluoride varnish. Systemic fluorides seem to have a limited role; mostly its primary effect is topical [87]. Many fluoride-containing products, such as toothpaste, mouthrinses, gels, and varnish can be used alone or in combination [90].

6.2.1. Toothpastes

Fluoride toothpaste is the most commonly used form of fluoride to provide a constant and low amount of fluoride in oral environment [91, 92]. Various fluoride compounds have been added to toothpaste either alone or in combination in the formulations, including sodium fluoride, sodium monofluorophosphate, amine fluoride, and stannous fluoride [90, 93].

The concentration of fluoride in toothpastes recommended by WHO is between 1000 and 1500 parts per million (ppm F). In many countries, toothpastes containing low fluoride (usually 450–500 ppm fluoride) are marketed for children. High fluoride containing toothpaste more than 1500 ppm (up to 5000) is commonly prescribed for adults at increased risk of caries [91]. Higher fluoride containing toothpaste provides more protection against caries [90, 94].

American Academy of Pediatric Dentistry (AAPD) recommended that using a smear or rice-size amount of fluoridated toothpaste is appropriate for children under 3 years old, and a pea-size amount of fluoridated toothpaste is appropriate for children 3–6 years old [95]. However Marinho et al. [90] recommended that children no more than 6 years of age should be supervised when brushing their teeth, and that no more than a pea-size amount, approximately 5 mm, should be used. Teeth should be brushed twice a day so that the toothpaste has a better effect. Moreover, rinsing with water must be held at bare minimum or it should not be done at all [95].

The widespread use of fluoride-containing toothpastes has caused a decline in tooth caries incidence. There has been a recently introduced additive, which is called Arginine, for toothpaste and other dental care products containing fluoride. Arginine is an amino acid that occurs naturally in a range of food products and in the saliva [96]. When applied in oral cavity, arginine is deaminated by the arginine deaminize system in saliva, producing ammonia, which is highly alkaline and leads to an increase in the pH in the oral biofilm, so that plays an active role with an insoluble calcium compound, and sodium monofluorophosphate for remineralization of WSLs [82, 97].

According to the statement of Zero [98], rinsing with tap water following the tooth-brushing, which is a widely seen practice, decreased oral fluoride retention considerably. Through the suggestion of this finding, the practice of brushing with fluoride toothpaste and a fluoride containing mouthrinse afterwards—used in combination—may be advantageous.

6.2.2. Fluoride mouthrinses

Fluoride mouthrinses have been successfully used to prevent dental caries and management of WSLs in children. Marinho et al. [99] suggested that supervised regular use of fluoride mouthrinse by children and adolescents is associated with a large reduction in caries increment in permanent teeth. Both daily uses of mouthrinses containing 0.05% NaF (226 ppm) and weekly rinsing programs with 0.2% NaF (900 ppm) were found to decrease the incidence of enamel demineralization. Because of the risk of fluoride ingestion, mouthrinsing is not recommended for children under 6 years old.

6.2.3. Fluoride varnishes

Fluoride varnishes were developed to make the contact time longer, to bond to the enamel for grater periods and prevent the immediate loss of fluoride after application. Therefore, they take the role of reservoir for slow release and facilitate greater fluoride uptake [100, 101]. Safety and efficacy methods of professionally practiced topical treatment for arresting active enamel caries are proven by fluoride varnishes. The fluoride concentration of fluoride varnishes is at a very high level (5% sodium fluoride, 22,600 ppm F). Since the amount of fluoride exposure can be kept under control, fluoride varnish application is thought to be safe [2]. They gradually release fluoride [102], and can be applied fast and effortlessly as well as setting in contact with moisture [103]. Dental prophylaxis in not necessary before varnish applications, thus chair time becomes shorter [81, 103]. Patients should avoid eating for 2–4 h after the application and to avoid brushing their teeth the night of the application, thus fluoride varnish may have more effect [104].

Douglas et al. [105] state that most guidelines recommended 5% (22,600 ppm F) concentration of sodium fluoride varnish. Even though there were differences upon the suggested frequency of application, applying fluoride varnish twice per year was a consensus.

AAPD guideline recommended that fluoride varnishes should be applied at least twice in a year for primary teeth and two or four times in a year for permanent teeth [95]. Marinho et al. [106] found that the use of fluoride varnishes two to four times a year, in permanent and primary dentition, leads to a considerable decrease in caries increment.

6.2.4. Fluoride gel

Fluoride gel can be applied both by professionals and by self-application of patients. In professional application, there are various methods for fluoride application. One of these methods is the application of fluoride with a mouth tray. In this method, fluoride gel is placed into a mouth tray and applied to entire dental arch at same time. Tray application is easily accepted by children. Other application methods include cotton balls and toothbrushes [91, 107]. The commonly used gels are 1.23% sodium fluoride gel (12,300 ppm F) and acidulated phosphate fluoride (APF) gel. The acidulation of this form is made with phosphoric acid at pH 3.0. The use of a fluoride vehicle with a lower pH value may extend the entrance of mineral ions into the body of the lesion. With this method, the microspores present on the surface of the enamel will not close because lamination due to fluoride of the surface layer will not happen. Thus, remineralization of the lesion will occur. On sound enamel surfaces, it acidulate dentifrices by mild etching. This results to an increase both in the micropores of the enamel layer and in the penetration of fluoride ions into the tooth [81]. Adding phosphate to an acid fluoride solution was practiced in order to depress calcium fluoride formation and increase fluoroapatite formation [100]. In pursuance of avoiding the likelihood of a low pH gel leading to etching in restorations, use of %2 neutral gels is recommended [91, 101]. Fluoride gel is professionally applied up to four times a year for 4 min [91, 101]. Due to risk of swallowing the fluoride gel, use in children under 6 years old is not recommended [108].

6.2.5. Fluoride foam

APF foam has the same concentrations (1.23%) and pH (3–4) of APF gel and applied in a same manner of APF gel [109]. Because of foam having a much lighter specific weight compared to a gel, it will take far less foam by weight in order to wholly fill a tray. Therefore, the amount of excess fluoride ingestion is reduced. It is seen that APF foam might be a beneficial alternative [110]. APF foam is professionally applied for 4 min and two times a year. This is effective in preventing dental caries in primary teeth [109, 111].

AAPD recommended that children with increased caries risk must undergo a professional fluoride treatment at least every 6 month. Since the risk categories might change in time, the types and intervals of preventive interventions should be adjusted accordingly [95].

6.3. Calcium-phosphate-based delivery systems

Calcium-phosphate based delivery systems are developed due to the difficulties of the solubility of calcium and phosphate remineralization systems; especially the presence of fluoride ions. They can be examined under three headings: crystalline, unstabilized amorphous, and stabilized amorphous formulations [73].

Crystalline calcium phosphate remineralizing systems have poor solubility of the calcium phosphate phases, so it is difficult to achieve enamel remineralization [112]. It is a problem that excessive amounts of calcium phosphate phases present in the mouth [113]. Calcium sodium phosphosilicates referred as bioactive glasses, are a kind of crystalline calcium phosphates derivatives [114] and show maximum remineralizing potential [115]. Narayana et al. [116] reported that calcium sodium phosphosilicate paste has shown to release ions and transform them into hydroxycarbonate apatite for up to 2 weeks.

Unstabilized amorphous calcium phosphate (ACP) formulation is developed by mixing calcium ions with phosphate ions to produce an ion active phase so that it could be precipitated as quickly as ACP or, in the presence of fluoride ions, amorphous calcium fluoride phosphate (ACFP). The desired effect is dissolution into the saliva and to promote tooth remineralization [117], but these unstabilized forms can cause dental calculus [73].

The casein phosphopeptides remineralization system is developed for replicating properties of the milk caseins and salivary statherin. Therefore, the casein phosphopeptide-stabilized amorphous calcium phosphate (CPP-ACP) [118] and casein phosphopeptide stabilized amorphous calcium fluoride phosphate complexes (CPP-ACFP) are developed [86].

CPP-ACP is a bioactive agent with a base of milk products able to bind calcium and phosphate ions to stabilize calcium phosphate in solution and to increase the level of calcium phosphate in dental plaque. CPP-ACP also adheres to hydroxyapatite, soft tissues, and supplies free calcium and phosphate ion, thereby helping to maintain reducing demineralization and promote remineralization by reforming into calcium phosphate crystals [119–122]. It can interact with hydrogen ions from the surface of the tooth and so it can penetrate to enamel's subsurface layer in order to produce mineral gain [30, 123]. Antibacterial and buffering efficacy has also been emphasized as interfering the growth and adherence of *Streptococcus mutans* and *Streptococcus sobrinus* to dental plaque [124].

It was used for the first time in 2009 to treat WSLs [125]. There have been many studies evaluating the effectiveness of fluoride and CPP-ACP in recent years and the positive effects of this in secondary prevention of WSLs has increased noticeably.

Andersson et al. [126] observed that daily topical application of CPP-ACP for 3 months followed by a 3-month period of daily tooth brushing with fluoridated toothpaste helped in the complete elimination of the post-orthodontic WSLs. They stated that visual evaluation suggested an esthetically more favorable outcome of the ACP treatments. Bailey et al. [125] claimed that CPP-ACP is effective when used for 12 weeks after debonding according to QLF and digital photographs. Even Brochner et al. [127] found usefulness of MI Paste when used for 4 weeks after debonding.

Robertson [128] has shown that according to the evaluations with intraoral digital photographs of 50 patients, MI Paste (GC America) (CPP-ACP containing paste) significantly reduced the incidence of WSLs during orthodontic treatment when used for 3–5 min each day at night after brushing for 3 months. Akin et al. [7] found that CPP-ACP can be more beneficial than fluoride rinse for postorthodontic remineralization with 58% reduction in the WSLs in 6 months.

Recent findings of a 12-week clinical study showed that topical applications of 10% CPP-ACP paste twice a day as an adjunct to a standard oral hygiene program significantly improved the appearance and remineralization of WSLs [89].

Contrary, there are studies reporting that CPP-ACP did not appear to be more effective than 1450 ppm fluoridated toothpaste in improving the appearance of WSLs after 36 months [129].

In the presence of fluorides, the formation of CPP-ACFP nano-complexes occurs and when the pH falls, the dissolution of the nano-complex leads the formation of calcium ions, phosphate ions, and neutral species $CaHPO_4$ and HF [130]. The synergistic effect of CPP-ACP and fluoride results in increased concentration of bioavailable calcium and phosphate ions in reducing the WSLs [131]. They produce a larger and more rapid remineralization of WSLs [132]. Llena [132] observed that 4-week use of CPP-ACFP is superior to fluoride varnish in remineralizing smooth surface WSLs. There is another study supporting these results as CPP-ACPF on daily basis had better remineralization potential than once professional application of fluoride varnish and twice daily use of fluoride toothpaste [86].

However, Beerens et al. [133] indicated that the use of CPP-ACFP crème for 12 weeks has no clinical advantage over normal hygiene in the remineralization of WSLs. They also reported that the percentages of aciduric bacteria and *S. mutans* decreased significantly both in CPP-ACFP and control groups, but they found no differences between groups. Similarly, Huang et al. [122] observed that CPP-ACFP does not appear to be more effective than normal home care in improving the appearance of WSLs over an 8-week period. The use of CPP-ACFP in subsurface enamel lesions due to orthodontic fixed appliance treatment does not provide additional improvement measured by QLF imaging, microbiological composition as well as by digital oral photographs [134].

Tooth Mousse/MI Paste (GC, Tokyo, Japan) is a topical remineralizing cream containing CPP-ACP (10% w/v). It is suggested to be applied on tooth surfaces twice a day after brushing. The patients should refrain from drinking or eating for 30 min subsequent to application. In addition high fluoride toothpaste should be used for 6 months in order to succeed in treating postorthodontic demineralized WSLs [121].

In a recent review, it was concluded that CPP-ACP products did not show any significant benefits over brushing with fluoride toothpaste in the prevention of demineralization because of the limited quality of evidence. Also, there is insufficient evidence for the use of fluoride-containing formulation. Further well-designed randomized controlled trials are required to determine efficiency of these systems for the prevention and treatment of early dental caries [135].

6.4. Polyols

Polyols are the alcohol derivatives of sugars, which are metabolized more slowly than sucrose by the oral bacteria. This reduces the risk of caries. They were first developed for use in diabetic products, but nowadays they are used in sugar free products like chewing gum, chocolate, boiled sweets, and biscuits. Polyols are "bulk sweeteners" which include xylitol, sorbitol, mannitol, maltitol, and lactitol [136].

Especially, xylitol provides an anti-caries efficacy on dental plaque and cariogenic microorganisms [137]. This reduces mutans streptococci (MS) levels by disturbing the energy production process and leads to cell death [138]. It also reduces the adhesion and acid production of these microorganisms present in dental plaque and saliva [139, 140]. Xylitol is more unique than the other sugar alcohols because it promotes mineralization by increasing salivary flow rate and is nonfermentable by oral bacteria [141]. It was shown that xylitol exhibits a dose- and frequency-dependent effect and it is safe [142, 143].

In an *in vitro* enamel lesion remineralization study, Makinen and Soderling [144] have proposed that very high concentrations of sorbitol and xylitol may influence calcium bioavailability, so it can support the remineralization process of subsurface lesions of enamel.

Miake et al. [145] investigated the effects of remineralizing solutions; with and without 20% xylitol, for 2 weeks on artificially demineralized enamel. They indicated that xylitol could influence remineralization in the deeper layers of demineralized enamel by facilitating Ca^{2+} movement and accessibility into the lesion.

A long-term study evaluated daily intake effects of erythritol, xylitol, and sorbitol on the development of enamel and dentin caries. It was found that the erythritol group showed a lower number of caries lesions than the xylitol or control groups and the longest duration of caries formation time [146].

Several studies indicated that using chewing gums containing xylitol controls cariogenic bacteria and plaque acidogenicity, and provide controlling caries increment [147, 148]. Sengun [149] reported that xylitol lozenges significantly helped neutralizing the acidity of dental plaque in patients undergoing fixed orthodontic appliance.

In contrast to these studies, Shen et al. [150] purposed that polyols (xylitol, sorbitol, maltitol, and mannitol) do not promote remineralization of enamel subsurface at physiologically relevant concentrations by forming Ca^{2+}-polyol complexes and facilitating calcium uptake into the lesion. Also, it has been shown that daily consumption of chewing gum containing CPP-ACP reduces the level of salivary *S. mutans* more than xylitol chewing gum [151].

More randomized controlled clinical trials are required for understanding the mechanisms of action, resistance, suitable delivery vehicles, and caries-preventive effects of xylitol [152]. The American Academy of Pediatric Dentistry (AAPD) supports the use of xylitol and other sugar alcohols as non-cariogenic sugar substitutes. However, this underlines the lack of consistent evidence showing significant reductions in *S. mutans* and dental caries in children, and adds that the high dose and high frequency of xylitol used in clinical trials may be unrealistic in clinical practice [153].

6.5. Chlorhexidine

Chlorhexidine is a commonly used cationic bisbiguanide agent with a broad range of antiseptic effect [154]. The efficacy and antiplaque effect of the solution in the control and management of biofilms has been proved in gingivitis [155], but there is not enough evidence in preventing initial caries lesions or the reduction of mutans streptococci levels [156, 157]. The inconclusive results of some studies have shown that chlorhexidine varnishes are effective in decreasing the prevalence of caries while others have not during orthodontic treatment [158–160]. It is likely that varnishes are more effective due to higher chlorhexidine concentration and longer contact time with the tooth surface [161, 162]. Chlorhexidine has bacteriostatic and bactericidal effects on *Streptococcus mutans* [163] and inhibits acid production in bacterial plaque; so during sucrose challenges, it reduces the fall in pH [164]. It was assumed that its remineralization effect on WSL's might be due to electrostatic links with hydroxyapatite's phosphate groups causing precipitation of phosphate salts on demineralized enamel surface [165]. When compared with weekly application of fluoride varnish period of 3 months, it was found that both were effective in controlling WSLs adjacent to orthodontic brackets but fluoride showed a faster remineralization [166]. The combined use of fluoride and chlorhexidine varnish was shown to be more effective in active WSLs than the use of one alone [167]. Studies using chlorhexidine vehicles alone or in combination with other agents are very limited, and a majority of the cases did not show a statistically significant reduction.

6.6. Laser

It has been shown that the use of laser irradiation is effective for caries prevention recently [168]. The mechanism is explained by decreased enamel permeability and alterations in the chemical composition and surface morphology for increased acid resistance of enamel exposed by laser irradiation [169, 170]. Melting and recrystallization of enamel surface cause reduction of permeability and the solubility of enamel, and thus prevent demineralization [171–174]. However, when laser is applied at high energy levels, it may cause undesired changes like cracks, glazed surfaces, columns separated by voids in the enamel surface during cooling [175, 176]. Irradiation of laser creates microspaces on the surface of the enamel so the released ions are trapped, and minerals are deposited into the enamel tissues [177]. It has been shown that using laser with topical fluoride leads a synergistic effect like increased uptake and less consumption of fluoride and decreased dissolution rate of the enamel [178, 179]. Also, the combination of laser and fluoride increase enamel acid resistance [180, 181] and transformation of hydroxyapatite to fluoroapatite [169].

Erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser is strongly absorbed by the hydroxyapatite of tooth structure and it does not ablate the surface. It only changes chemical composition of the enamel [182]. Nd:YAG laser irradiation was demonstrated to be effective in preventing occlusal caries in pits and fissures of primary teeth by low energy level [183]. CO_2 laser was also effective in the control of demineralization, with the advantages like being quick, comfortable, and simple application, especially in children, considering the difficulty of using a fluoride [184]. More long-term studies are required for understanding the longevity of the laser therapies in preventing caries and remineralization effect on WSLs [179].

6.7. Probiotics

Probiotic bacteria are defined as "living microorganisms that ensure a health benefit for the host when administered in sufficient amounts" by the World Health Organization (WHO) [185]. These bacteria mechanisms of action, which are candidates for bacteriotherapy, are still an open question, but it is known that they can produce bacteriocins against pathogenic bacteria. They also have local and systemic effects involving immune-modulation, modulate the inflammatory response, competitive inhibition, and binding instead of pathogens [186, 187]. Probiotic's can be delivered in milk, yogurt, cheese, ice cream, tablets, lozenges, powder, and drops. No negative side-effects for the probiotic usage were reported [188]. It was stated that probiotics may have a positive effect on reducing the mutans streptococci counts and this may cause a positive effect on the development of caries [189].

The study by Näse et al. [190] in preschool children milk containing *Lactobacillus rhamnosus* GG showed decrease in dental caries development; especially in the age group with the 3–4-year-olds, with a fraction of 60%. They suggested 5-day a-week intake of probiotic for reducing risk for caries. Also, Stecksen-Blicks et al. [191] evaluated the effect of milk supplemented with *L. rhamnosus* and fluoride for 21 months on enamel and dentine caries, and concluded that daily consumption of milk containing probiotic bacteria and fluoride reduced caries in preschool children with a prevented fraction of 75%. The disadvantages associated with its usage are effect of the probiotic will disappear when the patient discontinues its use [186], and using a single group of bacteria is partly relevant for microbial shift to the biofilm structure with aciduric phenotypes [188].

There is a need for long-term and large-scale trials examining the positive effect of these products to adopt bacteriotherapy for preventing and controlling caries and also determining the most appropriate species, treatment time, the ideal concentration, and vehicle [189, 192].

6.8. Sealants

Sealant applications to the enamel surfaces adjacent to orthodontic brackets during orthodontic treatment to form a physical barrier for acidic conditions was investigated by researchers and conflicting results has been reported. Some studies showed a caries inhibition effect of sealant application [193, 194], while others did not and also found high cost [195–197]. Durability of sealants may vary due to mechanical abrasion from mastication and brushing. These factors cause sealant abrasion [195, 198], so sealant preservation should be evaluated with 3-, 5-month periods and renewed if necessary [199]. Repeated applications are recommended for preventing WSLs formation effectively [200]. Also, filled resin sealants may be preferred due to their wear resistance instead of unfilled resin sealants to provide a better protection as a physical barrier but at this time removal after treatment can cause problems [201, 202]. Glass ionomer cements were suggested as enamel surface sealants due to their property of better prevention of surface lesion formation [19]. It has been reported that excessive sealant material may cause retention sites for biofilm and new sites for caries around the brackets [203]. Further well-designed *in vitro* and *in vivo* studies should be performed to evaluate long-term effects and find more high-level evidence to guide the best clinical decision to use resin sealant [19, 204].

6.9. Tooth bleaching agents

Vital bleaching was recommended to camouflage WSLs that are seen after the fixed appliance of orthodontic treatment [205]. It is a minimal invasive conservative approach and provides a more uniform appearance [206], but the most important reason for not having a wide use is that microhardness of sound and demineralized enamel surfaces may decrease after bleaching treatment [207]. Therefore, the risk of developing caries increases [208].

6.10. Microabrasion

Enamel microabrasion treatment can improve enamel surface texture and remineralization and eliminate superficial staining or defects [209, 210]. This technique includes hydrochloric acid and pumice application to the enamel, which removes approximately 100 μ from the surface layer. The structure of this microabraded enamel surface appears polished because of no interprismatic space and it is more resistant to bacterial colonization and demineralization [211, 212]. Some researchers reported that the microabrasion technique can reduce the size of white spot lesions by 83% and they concluded that it could be a treatment option for post-orthodontic demineralized enamel lesions [213]. While, another group of researchers contended that the first option should be conservative methods such as topical fluoride application. But if the problem still persists, microabrasion can be the treatment choice [214]. Also, Pliska et al. [8] demonstrated that microabrasion treatment successfully reduces white spot lesions regardless the CPP-ACP paste. However, there is a limitation to its use. It was reported that the technique is effective if the lesion sizes do not exceed from 0.2 to 0.3 mm in depth [215].

6.11. Ozone

Ozone application due to its oxidizing power and a reliable microbiocidal effect in the gaseous or aqueous phases can be considered as an alternative treatment method [216]. It can reduce the total number of microorganisms [217] by breaking up the cell walls of bacteria, viruses, and fungi, and also kills the acid-producing bacteria causing decay [218]. It was reported that ozone application can reduce *Streptococcus mutans* and *Streptococcus sobrinus* counts on saliva-coated glass beads [217]. However, this treatment method can only remove the microorganisms and stop the demineralization activity only in the outer half of enamel lesions [219]. According to a systematic review published recently, ozone application's clinical and cost effectiveness are still unknown; as well as the optimal concentration, application period, and how long effects might last, how deep it might penetrate, or whether having other side effects. More studies and evidence are needed to answer these questions as in the example of the application of ozone gas to decayed teeth is effective in preventing progression of dental caries, and ozone should not be considered as an alternative in general practice [220].

6.12. Resin infiltration

Resin infiltration is a technique used in improves the appearance of WSL. An opaque appearance of WSL is associated with the scattered of light as it passes through the lesion body. Scattering is caused at interfaces between two components with different refractive indices (RI), enamel (RI 1.62–1.65), water (1.33), or air (1.00). During the enamel-air interface, larger scattering is produced (**Figure 2**). Thus, early lesion stages need drying to be visually detected, as the RI of water is closer to that of enamel compared with air. Therefore, dehydrated enamel would show a decrease in translucency (**Figure 3**) [221, 222].

Resin infiltration technique obstructs the pores that provide diffusion pathways for acids and dissolved minerals in enamel. Thus, it prevents acid penetration into the lesions. Unlike fissure sealants, this technique creates the diffusion barrier inside the enamel lesions. Fissure sealants only form a barrier on the enamel lesions. Thus, resin infiltration could strengthen

Figure 2. Patient with white spot lesions at the bucco-cervical surfaces before application of resin infiltration technique.

Figure 3. Rubber dam isolation.

the enamel structure and prevent cavitation or breakdown of enamel surface [223]. Moreover, lesion progression slowed down or even arrested [221].

Resin infiltration material (Icon, DMG; Hamburg, Germany), consist of triethylene-glycol-dimethacrylate-resin and has high penetration coefficient, high surface tension, and low contact angle with enamel that facilitates penetration of lesion body of carious enamel [224]. The hypermineralized superficial layer blocked penetration of resin infiltrant into the lesion body. To facilitate resin penetration into the lesion body, 15% hydrochloric acid gel applied to hypermineralized superficial layer (**Figure 4**) [225]. Paris et al. [226] concluded that etching for 2 min with 15% hydrochloric acid gel led to deeper resin penetration of lesion body than etching with 37% phosphoric acid gel.

Figure 4. Application of icon etch.

After acid etching procedure, ethanol is applied for 30 s to remove the water from the lesion body (**Figure 5**); so that lesion desiccation is provided and resin penetration into the pores is facilitated by increased surface free energy [227, 228]. Paris et al. [228] showed that application of ethanol is an important step as pretreatment in preparation for resin infiltration.

Having completed the preparation of the lesion, a resin infiltrant is applied for 3 min on the lesion surface to occlude the porous of carious lesion, and to reduce diffusion of acids and minerals. Meyer-Lueckel et al. [229] reported that 3 min application of an infiltrant seems to be sufficient to achieve an almost complete penetration of natural caries lesions *in vitro*. Then excess resin was removed with cotton wad, before light curing [227]. Paris et al. [203] suggested that excessive material could be clinically a disadvantage, since sealants margins and excess resin could provide retention sites for biofilm and new caries lesion.

As a positive side effect of this application, this material was applied enamel lesions lose their whitish-opaque color appearance and look similar to sound enamel. Hence, this treatment could be used for arresting enamel lesions as well as improving the esthetic appearance of buccal WSLs [227]. The masking of enamel caries is caused by infiltrating the lesions by using resins with a similar refractive index (RI of infiltrant: 1.52) as apatite crystals (**Figures 6** and **7**). Thus, light scattering is reduced and visual color differences to enamel decreased [221].

Kim et al. [230] reported that resin infiltrant was wholly masked in 61% of the teeth, partially masked in 33% of the teeth and no change was observed in 6% of teeth in post orthodontic

Figure 5. View after rinsing of icon etch and ethanol application.

Figure 6. View after application of resin infiltrant and allowing penetration for 5 min.

Figure 7. Intraoral photographs taken after 1 week from completion of resin infiltration.

defects. They also concluded that masking effect of resin infiltrant is depends on depth of the lesion and activity. When the lesion does not reach deeper and the superficial layer is thinner, successful results are obtained with this application.

7. Conclusion

The WSLs may become less noticeable spontaneously over a period of 5–12 years [231]; however, natural remineralization mechanism by saliva involving mineral gain in the surface layer of enamel has little improvement on the esthetic and structural properties of the deeper lesions [73]. Within the limitations of the available data, it may be concluded that there is a need for examining the most appropriate remineralizing agent, treatment, and vehicles in order to speed up this repair process of the deeper parts of the WSLs for better esthetic and structural reinforcement.

Author details

Ceren Deveci[1], Çağdaş Çınar[2] and Resmiye Ebru Tirali[3]*

*Address all correspondence to: ebru_aktepe@hotmail.com

1 Department of Paediatric Dentistry, Faculty of Dentistry, Çukurova University, Adana, Turkey

2 Department of Paediatric Dentistry, Faculty of Dentistry, Gazi University, Ankara, Turkey

3 Department of Paediatric Dentistry, Faculty of Dentistry, Baskent University, Ankara, Turkey

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This book provides information to the readers starting with the history of oral hygiene manners, and modern oral hygiene practices. It continues with the prevalence and etiology of caries and remedy of caries through natural sources. Etiology of secondary caries in prosthetic restorations and the relationship between orthodontic treatment and caries is addressed. An update of early childhood caries is presented. The use of visual-tactile method, radiography and fluorescence in caries detection is given. The book finishes with methods used for the prevention of white spot lesions and management of caries.

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