

# **EGAS MONIZ UNIVERSITY INSTITUTE**

## **INTEGRATED MASTER'S DEGREE IN DENTAL MEDICINE**

### **WHITE SPOT LESIONS IN ORTHODONTICS: COMPARISON OF THE IMPACT OF FIXED ORTHODONTICS APPLIANCES VERSUS ALIGNERS**

Thesis submitted by

**Mathilde Cretel**

In partial fulfilment of the requirements for the degree of Master's in  
Dental Medicine

**June 2025**



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## **ABSTRACT**

Orthodontics is a specialty of dentistry that focuses on dental and facial aesthetics and harmony by correcting or improving dental, occlusal, and joint relationships.

In comprehensive orthodontic treatment, there are two main types of appliances: conventional fixed appliances, which consist of brackets and wires, and removable appliances in the form of thermoformed plastic trays, known as aligners. The latter have emerged in recent decades, significantly transforming orthodontic treatment by offering a more aesthetic and removable alternative to fixed appliances.

Patients often seek orthodontic treatment to improve or correct their dental or facial aesthetics. The treatment process, whether fixed or removable, can have side effects on oral health that should not be overlooked. One of the most common concerns is the development of white spot lesions (WSLs), which are areas of enamel demineralization caused by prolonged plaque accumulation. Their whitish appearance results from an optical effect due to mineral loss in the surface and inner layers of the enamel, and they appear as well-defined white or brownish spots.

WSLs are frequently observed during fixed orthodontic treatment, particularly around brackets, due to the increased difficulty in maintaining proper oral hygiene and the greater accumulation of bacterial plaque in these areas. They can also occur in orthodontic treatments with aligners, although oral hygiene is generally easier to maintain with this approach.

This narrative review aims first to define white spot lesions and their etiology. It will then provide a brief overview of the two main types of orthodontic treatment, followed by a comparison of WSLs prevalence between them. Finally, prevention and treatment strategies for WSLs will be discussed.

**Keywords:** Aligners; Fixed Orthodontic Treatment; White Spot Lesions; Hygiene oral



## RESUMO

A ortodontia é a especialidade da medicina dentária que se centra na estética e na harmonia dento-facial, corrigindo as relações dentárias, oclusais e articulares.

No tratamento ortodôntico integral, existem dois tipos principais de aparelhos: os aparelhos fixos ditos convencionais, com fios e brackets ortodônticos, e os aparelhos que o paciente pode remover em forma de moldeiras de plástico termoformáveis denominados alinhadores. Estes apareceram nas últimas décadas, transformando significativamente a abordagem do tratamento ortodôntico ao oferecer uma alternativa estética e removível em comparação com os aparelhos fixos.

Frequentemente, os pacientes optam por um tratamento ortodôntico para melhorar ou corrigir sua estética dentária ou facial. No entanto, o tratamento ortodôntico pode apresentar efeitos secundários para a saúde oral do paciente que não devem ser menosprezados. Entre esses, encontram-se as lesões de manchas brancas do esmalte (WSLs), constituídos por áreas de esmalte desmineralizado que surgem frequentemente após uma acumulação prolongada de placa dentária. O seu aspeto esbranquiçado é um efeito ótico devido à perda de minerais nas camadas superficial e interna do esmalte, aparecendo como manchas brancas ou castanhas com contornos bem definidos.

As WSLs são encontradas durante o tratamento ortodôntico fixo, sobretudo em redor dos brackets, resultantes da dificuldade acrescida de manutenção de uma higiene oral adequada e por maior retenção de placa bacteriana em redor dos mesmos. Nos tratamentos ortodônticos com alinhadores também são encontradas WSLs, apesar da higiene oral ser mais facilitada.

O objetivo desta revisão narrativa será, antes de mais definir as lesões de manchas brancas e a sua etiologia. Uma descrição sucinta dos dois tipos de tratamento ortodôntico será previamente realizada, seguida de uma comparação entre ambos na prevalência das WSLs. Finalmente, as estratégias de prevenção e tratamento das WSLs serão abordadas.

**Palavras-chave:** Alinhadores; Tratamento Ortodôntico Fixo; White Spots Lesions; Higiene oral



## RÉSUMÉ

L'orthodontie est une spécialité de la médecine dentaire qui se concentre sur l'esthétique et l'harmonie dentofaciale en corrigeant ou en améliorant les relations dentaires, occlusale et articulaire.

En orthodontie, deux types d'appareils sont principalement utilisés : les appareils fixes conventionnels avec fils orthodontiques et bagues et les appareils amovibles sous forme de gouttières en plastique thermoformables (aligneurs). Ces derniers, apparus au cours des dernières décennies, ont révolutionné la prise en charge orthodontique en offrant une alternative plus esthétique, confortable et discrète.

Les patients entament généralement un traitement orthodontique afin d'améliorer ou corriger leur esthétique dentaire ou faciale. Toutefois, ce traitement, qu'il soit fixe ou amovible, peut avoir des conséquences plus ou moins dévastatrices pour l'environnement buccal du patient, qui souvent n'en a pas conscience initialement. Parmi les conséquences négatives, nous pouvons retrouver les lésions de taches blanches (WSLs) qui sont des zones d'émail déminéralisé suite à une accumulation prolongée de plaque dentaire. Ces lésions crayeuses, blanches ou brunes, aux contours nets, résultent d'une perte minérale affectant les couches superficielles et profondes de l'émail.

Les WSLs sont fréquemment observées autour des brackets en traitement fixe, en raison des difficultés d'hygiène qu'ils induisent. Bien qu'ils soient supposés faciliter l'entretien de l'hygiène bucco-dentaire, les WSLs sont également retrouvés lors des traitements orthodontiques amovibles par aligneurs.

L'objectif de cette revue narrative est, dans un premier temps, de définir les lésions de taches blanches, puis de présenter les deux principaux types de traitement orthodontique. Une comparaison de leur influence sur la prévalence des WSLs sera proposée, suivie d'une analyse des stratégies actuelles de prévention et de prise en charge de ces lésions.

**Mots-clés** : Aligneurs; Traitement Orthodontique Fixe; White Spots Lesions; Hygiène orale



## TABLE OF CONTENTS

<b>I.</b>	<b>INTRODUCTION.....</b>	<b>15</b>
1.1	Contextualization and justification of the work .....	15
1.2	Objectives .....	16
1.3	Review methodology.....	17
<b>II.</b>	<b>DEVELOPMENT.....</b>	<b>19</b>
2.1	<b>White Spot Lesions (WSLs).....</b>	<b>19</b>
2.1.1	Description of WSLs .....	19
2.1.1.1	Definition and clinical characteristics .....	19
2.1.1.2	Clinical appearance and localization of WSLs.....	19
2.1.1.3	Difference between healthy and demineralized enamel .....	20
2.1.1.4	Diagnosis of WSLs.....	20
2.1.1.4.1	Visual diagnostic method .....	20
2.1.1.4.2	Complementary diagnostic methods .....	23
2.1.1.5	Differential diagnosis .....	27
2.1.1.5.1	Fluorosis .....	27
2.1.1.5.2	Traumatic Hypomineralization.....	28
2.1.1.5.3	MIH (Molar-Incisor Hypomineralization).....	29
2.1.1.5.4	Dental Hypocalcification.....	29
2.1.1.6	Etiology .....	29
2.1.1.6.1	The oral microbiome .....	29
2.1.1.6.2	The importance of saliva in enamel remineralization .....	31
2.1.1.6.3	Enamel demineralization process .....	32
2.1.2	WSLs in orthodontics .....	33
2.1.2.1	Prevalence.....	33
2.1.2.2	Risk factors .....	34
2.1.2.2.1	Systemic factors.....	35
2.1.2.2.2	Local factors .....	36
2.2	<b>Orthodontics.....</b>	<b>38</b>
2.2.1	Objective of orthodontic treatment.....	38
2.2.2	Description of orthodontic appliances .....	40
2.2.2.1	Fixed appliances .....	40
2.2.2.1.1	Labial and lingual brackets.....	40
2.2.2.1.2	Archwires.....	42
2.2.2.1.3	Ligatures and accessories .....	42
2.2.2.2	Clear aligners .....	43

2.2.3	Impact of fixed appliances on the development of WSLs.....	46
2.2.3.1	Dental plaque accumulation .....	47
2.2.3.2	Influence on the oral microbiome.....	48
2.2.3.3	Conclusion .....	49
2.2.3.4	Labial vs. Lingual fixed appliances.....	50
2.2.4	Impact of clear aligners on the development of WSLs .....	51
2.2.4.1	Dental plaque accumulation .....	51
2.2.4.2	Influence on the oral microbiome.....	53
2.2.4.3	Conclusion .....	54
2.2.4.4	Limitations.....	55
2.2.5	Conclusion of fixed Appliances vs. Clear aligners and the occurrence of WSL .....	56
2.2.6	Comparative table of the impact of fixed appliances and aligners on the occurrence of WSLs.....	59
<b>2.3</b>	<b>Prevention and management of WSLs .....</b>	<b>60</b>
2.3.1	Prevention of WSLs.....	60
2.3.1.1	Systemic prevention .....	60
2.3.1.1.1	Oral hygiene .....	60
2.3.1.1.2	Diet .....	61
2.3.1.2	Localized prevention .....	62
2.3.1.2.1	Fluoride.....	62
2.3.1.2.2	Fluoridated toothpastes.....	62
2.3.1.2.3	Fluoride mouthrinses and gels.....	62
2.3.1.2.4	Fluoride varnishes.....	63
2.3.1.2.5	Fluoride-Releasing materials.....	64
2.3.1.2.6	Products containing Casein Phosphopeptide - Amorphous Calcium Phosphate (CPP-ACP).....	64
2.3.1.2.7	Chlorhexidine .....	66
2.3.1.2.8	Sealants.....	66
2.3.2	Treatment of WSLs .....	66
2.3.2.1	Remineralization.....	67
2.3.2.2	Microabrasion.....	68
2.3.2.3	Resin infiltration .....	69
2.3.2.4	Bleaching .....	70
2.3.2.5	Laser .....	70
2.3.3	Conclusion .....	71
<b>III.</b>	<b>CONCLUSION.....</b>	<b>73</b>
	<b>BIBLIOGRAPHY.....</b>	<b>75</b>

## FIGURES INDEX

<b>Figure 1.</b> Photographic adaptation of QLF .....	24
<b>Figure 2.</b> Photographic adaptation of DIAGNODENT ® .....	25
<b>Figure 3.</b> Photographic adaptation of FOTI.....	26
<b>Figure 4.</b> Photographic adaptation of Electronic Caries Monitor ECM.....	27
<b>Figure 5.</b> Photographic adaptation of moderate fluorosis.....	28
<b>Figure 6.</b> Photographic adaptation of traumatic hypomineralization .....	28
<b>Figure 7.</b> Photographic adaptation of MIH.....	29
<b>Figure 8.</b> Schematic representation of the classification of bacteria present in a healthy oral cavity based on Gram staining and morphology .....	30
<b>Figure 9.</b> Schematic Representation of Dental Plaque Composition.....	32
<b>Figure 10.</b> Photographic adaptation of ceramic brackets on the maxillary teeth and metal brackets on the mandibular teeth. ....	41
<b>Figure 11.</b> Photographic adaptation of lingual brackets .....	41
<b>Figure 12.</b> Blue elastomeric ligatures on the maxillary teeth, and an alternation of elastomeric and metallic ligatures on the mandibular teeth.....	42
<b>Figure 13.</b> Photographic adaptation of intermaxillary elastics, hooks, and springs attached to metallic brackets.....	43
<b>Figure 14.</b> Photographic adaptation of an aligner.....	45

<b>Figure 15.</b> Photographic adaptation of an aligner with attachments .....	45
<b>Figure 16.</b> Photographic illustration of heavy plaque accumulation associated with fixed orthodontic appliances .....	47
<b>Figure 17.</b> Right, frontal, and left intraoral views following debonding of orthodontic brackets. WSLs are visible around former bracket sites.....	56
<b>Figure 18.</b> MI Paste Plus (GC America Inc, Alsip, Illinois) is a water-based, sugar-free crème containing Recaldent casein phosphopeptide–amorphous calcium phosphate and fluoride.....	65
<b>Figure 19.</b> White spot lesions before (A) and after (B) microabrasion .....	68
<b>Figure 20.</b> Resin infiltration provides a minimally invasive treatment approach to transform the outer surface of affected teeth into a more permeable layer with the help of hydrochloric acid (HCl) etching, and infiltrating the porous structure beneath it using a TEGMA-based, low-viscosity resin .....	69

## **TABLES INDEX**

<b>Table 1.</b> ICDAS II.....	21
<b>Table 2.</b> Classification of WSL.....	22
<b>Table 3.</b> WSLs prevalence according to treatment type, before and during treatment..	34
<b>Table 4.</b> Comparison of the effects of fixed appliances and aligners on oral health and the development of WSLs. ....	59



## **LIST OF ABBREVIATIONS**

**WSLs** – White Spot Lesions

**ICDAS** – International Caries Detection and Assessment System

**QLF** – Quantitative Light- induced Fluorescence

**FOTI** – Fibre Optic Transillumination

**ECM** – Electronic Caries Monitor

**MIH** – Molar-Incisor Hypomineralization

**TMJ** – Temporomandibular Joint

**CPP-ACP** – Casein Phosphopeptide - Amorphous Calcium Phosphate

**CPP-ACPF** – Casein Phosphopeptide - Amorphous Calcium Phosphate and fluoride

**RMGIC** – Resin-Modified Glass Ionomer Cements

**TEGDMA** – Triethylene Glycol Dimethacrylate



## **I. INTRODUCTION**

### **1.1 Contextualization and justification of the work**

Orthodontics is a dental specialty focused on dental and facial aesthetics and harmony, improving and/or correcting dental, occlusal, and joint relationships (1). In orthodontics, there are two main types of appliances: conventional fixed appliances and removable appliances.

One of the primary reasons patients seek orthodontic treatment is to enhance or correct their dental or facial aesthetics (2). However, undergoing orthodontic treatment, whether fixed or removable, can have negative consequences on oral health that should not be overlooked.

Conventional fixed orthodontic treatment involves brackets, which are bonded to the teeth, and an archwire that applies controlled forces to move them. This system makes oral hygiene maintenance more challenging, as it complicates tooth brushing and promotes plaque accumulation. The buildup of dental plaque can lead to undesirable effects on the teeth, such as the development of White Spot Lesions (WSLs) (3).

WSLs appear as whitish, opaque areas with irregular contours on the enamel surface. They result from a demineralization process induced by the activity of acidogenic bacteria present in dental plaque. Considered one of the main side effects of fixed orthodontic treatments, WSLs are closely associated with the presence of brackets and other orthodontic attachments. Numerous studies have demonstrated a direct link between the development of WSLs and the use of fixed orthodontic appliances (4,5).

In recent years, the demand for more aesthetic and comfortable orthodontic treatments among adult patients has increased significantly. More and more patients seek an alternative to traditional fixed appliances, often perceived as inconvenient and inaeesthetic. This search for more discreet solutions may have found an answer with the emergence of clear aligners (4). Aligners are transparent, flexible thermoformed trays that cover the entire dentition and may require the attachment of resin bonding elements on the teeth to enhance their effectiveness. Their success relies on active patient compliance, as they

must be worn for more than 20 hours per day to be effective (6). Thanks to their discreet and removable nature, aligners have become a popular choice, as aesthetics and facial appearance play a crucial role in today's society. Additionally, their removability allows patients to maintain better oral hygiene compared to fixed appliances, as they can brush their teeth more easily (6). However, despite these advantages, clear aligners are not without risks. While their removability might suggest a reduced risk of WSLs formation, recent studies indicate that they could, in fact, promote enamel demineralization. The resin attachments create plaque retention areas, facilitating biofilm accumulation. Moreover, prolonged wear, combined with the fact that aligners cover a large portion of the dental surface, may hinder the natural self-cleaning process of the teeth through saliva (6). This prolonged interaction with the dentition could disrupt the balance of the oral microbiome, altering its composition and metabolic functions, thereby increasing the risk of WSLs formation (7,8).

Not only do WSLs compromise the patient's dental aesthetics, but they can also progress into more concerning lesions, such as cavities. Although some WSLs may diminish or even disappear after the removal of orthodontic appliances due to the remineralizing effect of saliva, others can persist for much longer. Today, one of the greatest challenges in orthodontics is maintaining good oral health despite the difficulties associated with orthodontic appliances, to preserve periodontal health and ensure the success of treatment. This success also depends on the patient's active cooperation, particularly in maintaining strict oral hygiene and adhering to the practitioner's recommendations to prevent the development or worsening of WSLs (6).

## **1.2 Objectives**

The primary objective of this narrative review is to compare the influence of fixed orthodontic appliances and clear aligners on the occurrence of WSLs on tooth surfaces. By reviewing the existing literature, this study also aims to outline the different approaches to managing these lesions and the best practices for preventing their development, both from the patient's and the practitioner's perspective.

### **1.3 Review methodology**

As part of this narrative review, a comprehensive analysis of recent scientific literature was conducted. The article search was carried out using the following keywords: Aligners, Fixed Orthodontic Treatment, White Spot Lesions, and Oral hygiene. The selected publications span the period from 1997 to the present, with 1997 chosen as the starting point due to the introduction of orthodontic aligners in the United States. The review is based on studies published in English, French, and Portuguese, retrieved from databases such as PubMed, B-On, Medline, ScienceDirect, SciELO, and Google Scholar.



## **II. DEVELOPMENT**

### **2.1 White Spot Lesions (WSLs)**

#### **2.1.1 Description of WSLs**

##### **2.1.1.1 Definition and clinical characteristics**

Dental caries is a bacterial disease that, in its initial stage, typically manifests as white spots on the enamel, known as "white spot lesions" (WSLs). In dentistry, dental caries is the most common pathology affecting the global population at all stages of life (9).

##### **2.1.1.2 Clinical appearance and localization of WSLs**

WSLs are the earliest visible sign of enamel caries, appearing as non-cavitated lesions that can be detected with the naked eye when the teeth are dry. Clinically, these lesions present as opaque, milky white spots with diffuse borders on the smooth surfaces of teeth (10,11). They correspond to porous enamel areas caused by carious demineralization. It is essential to monitor these lesions closely, as they are not classified as active caries requiring restorative treatment but can progress into cavities if left unmanaged. Depending on the oral environment, these lesions may remain stable for a period and, in the best-case scenario, partially remineralize (12).

These white spots represent non-developmental decalcified areas that form when bacterial plaque accumulates on the enamel surface for an extended period. They can appear either as multifocal lesions or be localized to a single tooth (11). WSLs are primarily located on the labial surfaces of anterior teeth, particularly the lateral incisors, followed by the canines and central maxillary incisors, as well as the posterior mandibular segments (13). This specific distribution of WSLs can be explained by the relationship between salivary flow and susceptibility to demineralization. Areas that receive a high salivary flow, such as the posterior maxillary regions, are better protected due to the buffering and remineralizing properties of saliva. In contrast, the labial surfaces of anterior teeth and the posterior mandibular segments, which are less exposed to salivary flow, are more vulnerable to the development of WSLs (14).

### **2.1.1.3 Difference between healthy and demineralized enamel**

Healthy enamel is considered the most mineralized tissue in the human body, with 96% of its weight primarily composed of hydroxyapatite, an inorganic mineral made up of calcium and phosphate. The remaining 4% consists of organic tissues. In a demineralization process, the chemical composition of enamel is altered, leading to a reduction in its mineral phase, which is progressively replaced by organic fluids (15).

In the case of a WSL, the whitish discoloration results from mineral loss within the enamel, modifying how light is reflected. This appearance is also influenced by the difference in refractive indices between water and air, which fill the voids created in the porous enamel. The resulting irregular surface leads to a loss of enamel translucency and causes diffuse light reflection. These alterations in optical properties give the tooth its characteristic white spot appearance (16).

### **2.1.1.4 Diagnosis of WSLs**

#### **2.1.1.4.1 Visual diagnostic method**

Visual diagnosis is the primary clinical method used for identifying WSLs. Detection relies on a thorough examination, typically facilitated by drying the tooth, which enhances the visibility of mineral structure alterations in the enamel (17). To improve diagnostic objectivity, standardized classification systems have been developed, notably the International Caries Detection and Assessment System (ICDAS). This system was designed to provide clinicians, epidemiologists, and researchers with an evidence-based approach to assessing carious lesions, including both early-stage and more advanced caries, as well as WSLs, according to their severity (18).

This classification system enhances diagnostic consistency among clinicians while also simplifying the comparison of epidemiological studies and clinical trials on caries and WSLs. With the refinement of criteria, ICDAS has evolved into ICDAS II, offering an even more precise and detailed classification of lesions (Table 1) (19).

**Table 1.** ICDAS II (Inspired Banting et al., 2011)

Code	Description
0	Sound
1	First Visual Change in Enamel (seen only after prolonged air drying or restricted to within the confines of a pit or fissure)
2	Distinct Visual Change in Enamel
3	Localized Enamel Breakdown (without clinical visual signs of dentinal involvement)
4	Underlying Dark Shadow from Dentin
5	Distinct Cavity with Visible Dentin
6	Extensive Distinct Cavity with Visible Dentin

Stage 0 corresponds to healthy enamel with no signs of caries. The enamel remains intact and translucent, without any evidence of demineralization, even after prolonged drying (more than 5 seconds) (18). Some non-carious enamel anomalies (such as hypoplasia, fluorosis, or extrinsic stains) may be observed, but they are not considered carious lesions (19).

Stages 1 and 2 correspond to carious lesions confined to the enamel. In Stage 1, an initial visual change in the enamel is detected. A lesion that is invisible when the tooth is wet becomes perceptible after prolonged drying, appearing as a white or brown opacity. WSLs are typically classified in this stage, as they represent early and reversible demineralization without any structural loss of the enamel (19).




Stage 2 is characterized by a distinct visual change in the enamel. The lesion is visible on a wet tooth and remains apparent after drying. It is wider than the natural fissure or pit of the tooth, indicating advanced demineralization but without cavitation. Some progressing WSLs may reach this stage if left untreated, increasing the risk of developing a cavitated lesion (19).

From Stage 3 to Stage 6, caries involves both the enamel and dentin, with cavitation present (19).

WSLs primarily correspond to ICDAS Codes 1 and 2, representing early and reversible lesions. Early diagnosis of WSLs allows for intervention before they progress to cavitation (Code 3). The ICDAS II classification provides a precise diagnostic framework to assess caries progression. WSLs should be detected and managed at the earliest signs to prevent their progression to more advanced stages. Regular follow-ups and appropriate preventive treatments help preserve enamel integrity and avoid invasive restorative procedures (19).

In orthodontics, another commonly used index is Gorelick’s Index, which assesses the severity of WSLs based on the extent of the affected enamel surface. It classifies WSLs into four severity levels (Table 2) (5,6):

**Table 2.** Classification of WSL (Inspired Øgaard, 2008, Liu & Song, 2024)

<b>Class</b>	<b>Size and Intensity</b>	<b>Figures</b>
<b>Class 1</b>	No white spot lesion	
<b>Class 2</b>	Mild white spot lesion on the enamel surface covering less than one- third of the tooth surface	
<b>Class 3</b>	Moderate white spot lesion on the enamel surface covering more than one-third of the tooth surface	
<b>Class 4</b>	Severe white spot lesion on the enamel surface covering the entire surface of the tooth or presenting with cavitation	

This index is particularly relevant for monitoring the impact of fixed orthodontic treatments on enamel and allows for a standardized assessment of WSLs before and after treatment. Visual examination is a simple, quick, and non-invasive method, making it widely used in clinical practice. Nonetheless, it has several limitations (20). First, it has low sensitivity for early lesions. Indeed, the visual detection of non-cavitated lesions is challenging, as they are often invisible at an initial stage. Due to the anatomical structure of WSLs, their presence is often confirmed only when they have progressed deeper into the enamel. Second, there is inter-examiner variability. The sensitivity and specificity of visual diagnosis vary widely, which can lead to diagnostic errors depending on the clinician's experience (20). Lastly, there is a lack of quantitative evaluation. Unlike instrumental methods, visual examination does not allow for precise measurement of lesion depth or standardized monitoring of its progression.

To compensate for these limitations, visual diagnosis is often combined with radiography. Although its sensitivity for detecting early lesions is low, it can sometimes help confirm a visual diagnosis (20). However, its use remains limited in the context of WSLs due to radiation exposure and its poor ability to detect early superficial lesions (21).

Thus, visual diagnosis remains the first-line tool for detecting WSLs in clinical practice. However, its limitations in terms of sensitivity and reproducibility necessitate a complementary approach using other diagnostic methods, particularly more recent instrumental techniques. Early and accurate assessment of WSLs enables preventive and conservative management, which is essential to prevent their progression into cavitated lesions (9).

#### **2.1.1.4.2 Complementary diagnostic methods**

Although visual examination is commonly used, it has limitations, particularly in detecting initial or clinically non-visible lesions and in accurately assessing their progression. To overcome the limitations of visual detection, various complementary methods have been developed, improving the sensitivity and specificity of diagnosis (22).

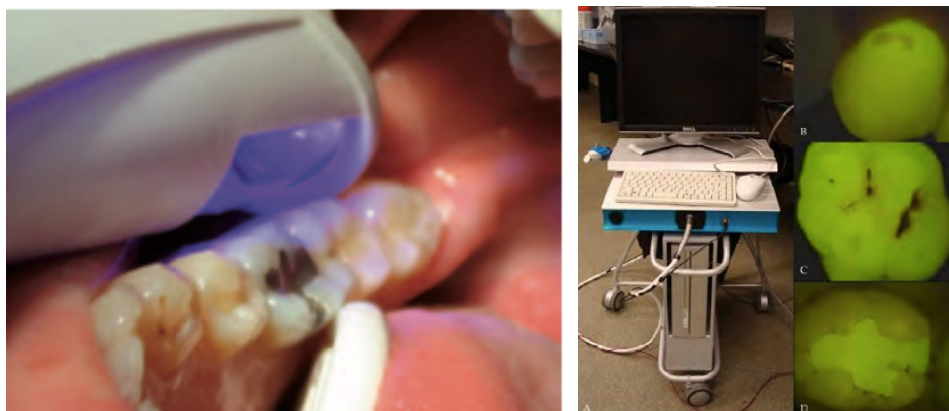
These techniques include tools based on:

- Fluorescence (QLF and DIAGNOdent®)
- Optical transillumination (FOTI)
- Electrical conductivity (ECM)

Quantitative Light-Induced Fluorescence (QLF) and DIAGNOdent® are two diagnostic methods that use fluorescence to detect lesions.

**QLF** is an advanced diagnostic technique that enables the detection and quantification of enamel demineralization. It is particularly effective for identifying and monitoring the progression of WSLs. This method relies on an intraoral fluorescence camera that illuminates the teeth with a specific blue light at 405 nm (20).

Healthy enamel contains naturally fluorescent minerals that emit a green light under this illumination. When demineralization occurs, this fluorescence decreases, revealing a darker area (23). The intensity of this fluorescence loss is directly correlated with the amount of mineral loss, allowing for an objective assessment of lesion severity. QLF enables precise monitoring of mineral variations, facilitating the observation of both remineralization and demineralization, and thus the progression of early carious lesions. However, this technology remains underutilized in clinical practice due to its high cost and the need for standardized conditions to ensure reliable measurements. Consequently, it is primarily limited to scientific studies (24).



**Figure 1.** Photographic adaptation of QLF (adapted from Baffi et al., 2012, A. Lussi & B. Angmar-Månsson, 2008).

**DIAGNOdent®** is a laser fluorescence device designed for the early and objective detection of demineralized lesions. It operates using a 655 nm diode laser, which interacts with the dental structure. In the presence of carious lesions, increased fluorescence is emitted, captured, and quantified by the device as a score ranging from 0 to 99:

0 → Low fluorescence (healthy enamel)

99 → High fluorescence (advanced lesion) (25)

This fluorescence originates from bacterial fluorophores, which are absent in healthy enamel. However, in very early lesions, these fluorophores are not yet present, which may limit detection by DIAGNOdent® (26).

Regarding the procedure, prior cleaning is recommended before any measurement to remove plaque and extrinsic stains, which could distort the results (27). Additionally, measurements vary depending on whether the tooth is dry or wet, necessitating a standardized protocol to ensure reliable monitoring. Under dry conditions, detection thresholds are higher (26).

DIAGNOdent® offers high sensitivity, allowing the detection of lesions that are invisible to the naked eye or imperceptible through tactile examination. It enables digital monitoring of WSLs progression, facilitating the assessment of remineralization treatments' effectiveness. However, it also has limitations. The high risk of false positives may lead to diagnostic errors. Therefore, it should not be used as a primary method but rather as a complement to visual and radiographic examinations (26).



**Figure 2.** Photographic adaptation of DIAGNODENT ® (adapted from Lussi & B. Angmar-Månsson, 2008).

**Optical Fiber Transillumination (FOTI)** is a diagnostic technique that detects variations in mineral density by transmitting light through the tooth (21). It utilizes a fine probe that emits a highly focused light beam (0.3 to 0.5 mm in diameter) directed at the tooth. In healthy enamel, the light is evenly diffused (28). However, in the presence of WSLs, the demineralized structure alters light diffusion, creating shadowed areas that are visible during clinical examination. The use of FOTI allows for the early detection of these anomalies before they progress into deeper carious lesions (21).

One of the main advantages of FOTI is its ease of use, speed, and low cost. However, its sensitivity is relatively low compared to more advanced imaging techniques. It is particularly effective for detecting surface lesions but is less reliable for assessing the exact depth of demineralized areas (28).



**Figure 3.** Photographic adaptation of FOTI (adapted from Baffi et al., 2012).

**The Electronic Caries Monitor (ECM)** is a diagnostic tool that measures the electrical conductivity of dental tissues to differentiate between healthy and demineralized enamel (21). Highly mineralized enamel exhibits high electrical resistance, whereas demineralized enamel shows increased conductivity due to the infiltration of saliva and electrolytes into its porous structure (27). ECM leverages this property to identify and quantify demineralization, enabling early detection of WSLs. Among the available devices, the ECM by Lode Diagnostic (Groningen, Netherlands) is one of the most widely used (26). However, its diagnostic accuracy varies depending on the dental surface examined. It is particularly effective on smooth surfaces, whereas its performance is more limited for detecting lesions on occlusal surfaces. Despite its high sensitivity, ECM remains a complementary tool to conventional methods such as visual examination

and radiography. Some studies suggest that its diagnostic reliability is lower than that of DIAGNOdent® for detecting occlusal lesions (29).



**Figure 4.** Photographic adaptation of Electronic Caries Monitor ECM (adapted from Lussi & B. Angmar-Månsson, 2008).

QLF, DIAGNOdent®, FOTI, and ECM are non-radiative and painless diagnostic methods that provide an alternative to conventional radiography. They enable early detection and precise monitoring of WSLs, thereby facilitating the implementation of appropriate preventive and therapeutic strategies. However, none of these methods can fully replace clinical and radiographic examinations. Instead, they serve as valuable complementary tools, enhancing the comprehensive management of WSLs in orthodontics.

#### **2.1.1.5 Differential diagnosis**

Establishing an accurate diagnosis of WSLs is crucial. These lesions can have various etiologies, yet their appearance remains similar. However, their therapeutic approach and treatment plan differ. It is therefore essential to distinguish carious WSLs from other types of white enamel spots unrelated to caries, such as those associated with fluorosis, traumatic hypomineralization, molar-incisor hypomineralization (MIH), and dental hypocalcification (29).

##### **2.1.1.5.1 Fluorosis**

WSLs can have a systemic etiology. Dental fluorosis is a pathological condition in which enamel becomes hypomineralized due to excessive fluoride intake during enamel mineralization in childhood. When fluoride is administered in small amounts via topical application, it can promote remineralization and prevent caries. However, excessive

fluoride intake can disrupt tooth formation, leading to reduced mineral content in the enamel and increased porosity. Fluorosis presents in varying degrees of severity and typically appears symmetrically as white lines with ill-defined margins (30).



**Figure 5.** Photographic adaptation of moderate fluorosis (adapted from Sampson & Sampson, 2020).

#### **2.1.1.5.2 Traumatic Hypomineralization**

Permanent teeth that succeed traumatized primary teeth often exhibit discoloration or enamel hypoplasia. Whether the trauma is physical (fracture, chipping) or chemical (periapical infection), periapical inflammation can interfere with the mineralization process, leading to an accelerated deposition of minerals. These lesions closely resemble those of fluorosis; however, they are generally asymmetrically located in the incisal third of the dental crowns, as trauma usually affects a single tooth (30).



**Figure 6.** Photographic adaptation of traumatic hypomineralization (adapted from Sampson & Sampson, 2020).

### **2.1.1.5.3 MIH (Molar-Incisor Hypomineralization)**

MIH is a qualitative enamel defect of systemic origin occurring pre- or neonatally. It manifests as porous areas characterized by small white-to-brown spots on the four first permanent molars, often accompanied by enamel opacities on the incisors. In contrast to typical WSLs, which are limited to the enamel surface, MIH lesions originate at the enamel-dentin junction (30).



**Figure 7.** Photographic adaptation of MIH (adapted from Sampson & Sampson, 2020).

### **2.1.1.5.4 Dental Hypocalcification**

Dental hypocalcification is a mineralization anomaly of the enamel that occurs before tooth eruption. It can be caused by genetic factors, complications during tooth development, or systemic diseases. Regardless of whether the tooth is dry or wet, the enamel exhibits an opaque appearance with whitish, yellowish, or brownish spots. This characteristic distinguishes these spots from carious WSLs, which become more visible when the enamel is dried (17).

### **2.1.1.6 Etiology**

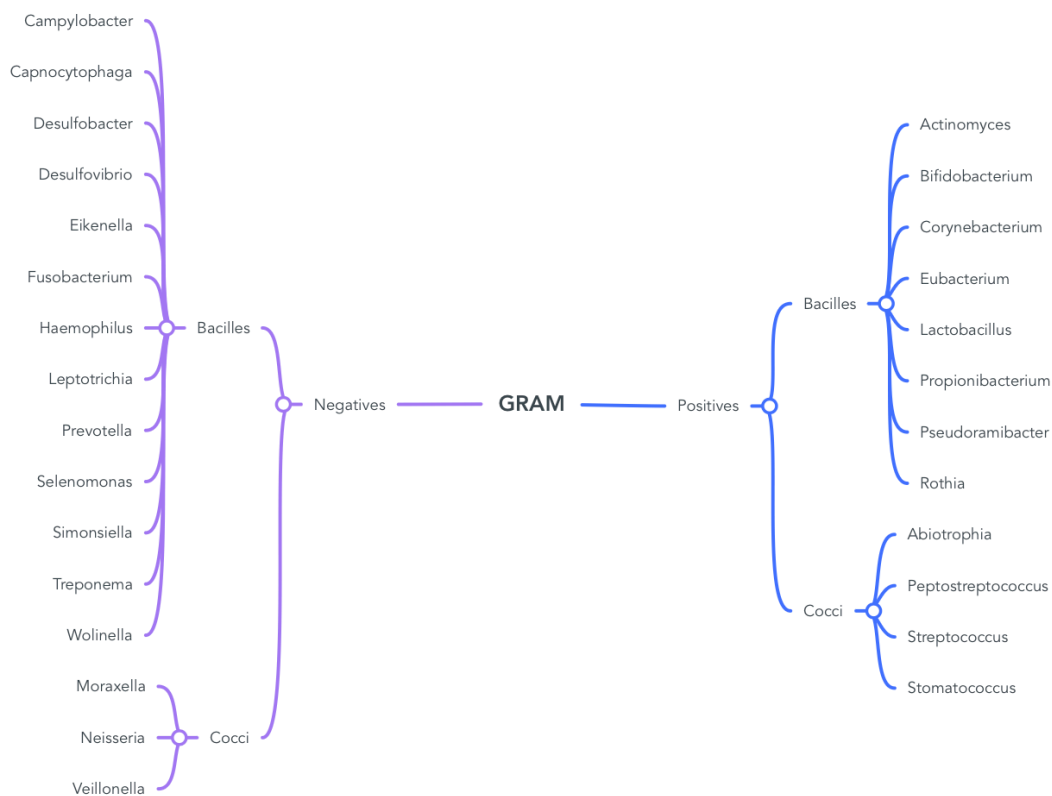
#### **2.1.1.6.1 The oral microbiome**

The oral microbiome refers to the collection of symbiotic, commensal, and pathogenic microorganisms coexisting within the oral cavity. The various surfaces of the mouth, including the teeth, tongue, gingival sulcus, and cheeks, provide a favorable environment

for microbial colonization. These surfaces host a diverse bacterial community, forming a bacterial biofilm (31).

In a healthy oral cavity, the predominant bacterial genera coexist in symbiosis (Figure 8). Through this dynamic balance, the oral microbiome contributes to both local and systemic health. However, any significant change in the local environment, whether physiological, pathological, or treatment-related, can disrupt this symbiotic relationship (4). This imbalance, known as dysbiosis, is a major contributing factor in the development of oral diseases such as dental caries, WSLs, gingivitis, and periodontal diseases (4,32).

However, in the presence of pathology, some microbial populations proliferate excessively, leading to an imbalance in this ecosystem (33).



**Figure 8.** Schematic representation of the classification of bacteria present in a healthy oral cavity based on Gram staining and morphology (Inspired by Marsh, 2000).

It has been observed that the presence of *Streptococcus mutans* and *Lactobacillus* in saliva is positively correlated with the prevalence of dental caries (34).

### **2.1.1.6.2 The importance of saliva in enamel remineralization**

Saliva is composed of 99.5% water, while the remaining 0.5% contains various inorganic and organic compounds, including salivary proteins such as histatins, mucins, and statherins. These proteins play a crucial role in maintaining oral balance and preserving dental integrity due to their antibacterial, antiviral, and antifungal properties (32,34).

First and foremost, saliva plays a crucial role in the natural self-cleaning process of teeth. Its consistency and flow facilitate the removal and dissolution of food residues and bacteria present in the oral cavity, thereby reducing the contact time of carbohydrates with the enamel on tooth surfaces. Additionally, saliva helps limit the formation of dental plaque, which is the primary triggering factor for WSLs. In a healthy individual, the average daily production of saliva is approximately 600 mL (34). However, saliva is not evenly distributed across all dental surfaces. The maxillary anterior teeth, being less exposed to saliva, are more susceptible to demineralization in the presence of dietary carbohydrates. In contrast, the lingual surface of the lower incisors and the buccal surface of the maxillary molars, where salivary flow is more abundant, are prime sites for tartar formation, reflecting an ongoing process of mineralization (14).

Furthermore, saliva plays a key role in maintaining oral pH balance through its buffering capacity, which neutralizes acids produced by acidogenic bacteria during the breakdown of fermentable carbohydrates. This defense mechanism primarily relies on the bicarbonate, phosphate, and urea systems, which help restore a stable pH after acidification caused by dietary intake or bacterial metabolism (34).

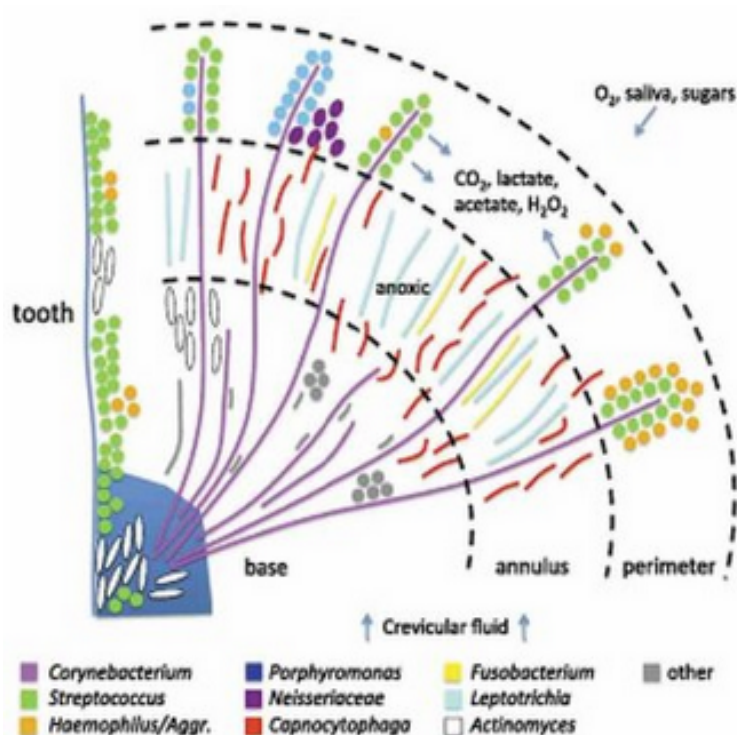
The bicarbonate buffering system, in association with carbonic acid, is the most effective in restoring intraoral pH to its normal range (between 6 and 7), with optimal activity between pH 4 and 7. However, when sugar consumption is excessive or frequent, the buffering capacity of saliva may be overwhelmed, causing the pH to drop below the critical threshold of 5.5. This environment promotes enamel demineralization and the formation of WSLs. Additionally, a low buffering capacity and insufficient salivary flow reduce the elimination of microorganisms and food residues within the oral cavity, limiting acid neutralization and WSLs remineralization, which in turn favors caries

development (9,35). The effectiveness of the buffering system can also be hindered by the thickness of dental plaque, which obstructs the diffusion of bicarbonate and phosphate ions.

Saliva serves as an essential reservoir of ions, including calcium ( $\text{Ca}^{2+}$ ), phosphate ( $\text{PO}_4^{3-}$ ), bicarbonate ( $\text{HCO}_3^-$ ), and, in some cases, fluoride ( $\text{F}^-$ ). These ions play a crucial role in the remineralization of dental hard tissues. Naturally present in saliva or supplemented through external sources such as fluoridated water and toothpaste, these minerals help repair early demineralization lesions caused by acids (36). This remineralization mechanism strengthens enamel and reverses the initial stages of its degradation. Therefore, maintaining good oral hygiene is essential to maximize the protective efficacy of saliva and prevent enamel deterioration.

### 2.1.1.6.3 Enamel demineralization process

Dental plaque on the surface of teeth is composed of acidogenic bacteria that ferment carbohydrates (sugars) from the oral cavity. This fermentation leads to the production of acidic substances (37).



**Figure 9.** Schematic Representation of Dental Plaque Composition (adapted from Olsen, 2008, under CC BY 4.0 license).

This acid production causes a decrease in salivary pH below the critical threshold of 5.5, disrupting the balance between remineralization, which decreases, and demineralization, which increases. This imbalance results in surface dissolution, specifically the breakdown of hydroxyapatite, leading to the demineralization of the superficial enamel (11). This process creates porosities within the enamel, making the surface rough and irregular, with a characteristic whitish and opaque appearance, typical of WSLs. These morphological alterations further promote bacterial adhesion and plaque retention, perpetuating a vicious cycle of demineralization. If this process continues, cavitated carious lesions will develop, eventually reaching the dentin. However, if WSLs are diagnosed at an early stage, when demineralization is still partial, they can undergo remineralization. This highlights the importance of early diagnosis and intervention (17).

Additionally, sucrose, a carbohydrate widely present in the global diet, is considered the most cariogenic sugar. It is essential to understand that not only the quantity of sugar consumed but also the frequency of consumption directly influences the risk of developing caries (37), particularly when the intake of fermentable carbohydrates is combined with inadequate oral hygiene.

Indeed, poor oral hygiene leads to the accumulation of bacterial plaque, which can be exacerbated by certain factors such as orthodontic appliances. Consequently, inadequate oral hygiene, combined with the use of devices that promote bacterial plaque retention, significantly increases the risk of developing WSLs (38).

## **2.1.2 WSLs in orthodontics**

### **2.1.2.1 Prevalence**

WSLs can develop both with and without orthodontic treatment, whether fixed or removable. Even before the initiation of orthodontic therapy, their prevalence is estimated to range between 10% and 40% among patients (6,39). Nevertheless, the risk of WSLs development significantly increases during orthodontic treatment, particularly with fixed appliances.

Recent scientific literature reports a wide variation in WSLs prevalence rates during orthodontic treatment, ranging from 2% to 97%, depending on the study and methodology

used (39). Notably, there is a significant difference based on the type of appliance. Fixed orthodontic appliances exhibit a higher prevalence rate, whereas aligners appear to be associated with a lower risk.

The table below summarizes these findings:

**Table 3.** WSLs prevalence according to treatment type, before and during treatment.

Type of treatment	Prevalence before treatment	Prevalence after treatment
No treatment	10 à 40 % (6,39)	-
Overall orthodontic treatment	-	2 à 97 % (39)
Fixed orthodontic appliances	-	30 à 72,9 % (6,16,38,39)
Aligners	-	1,2 à 35,5 % (6,40)

It is important to note that, compared to conventional fixed appliances, clear aligners are a more recent innovation. As a result, fewer studies have been conducted, leading to a limited body of evidence regarding certain aspects of these devices, particularly the prevalence of WSL development (6).

The variability in reported prevalence rates can be attributed to differences in detection methods and measurement criteria. Since WSLs identification depends on the diagnostic technique used, studies utilizing Quantitative Light-Induced Fluorescence (QLF) tend to report higher lesion prevalence compared to those relying solely on visual inspection (24).

Given the high prevalence of WSLs, it is essential for both patients and practitioners to focus on effective prevention and management strategies to minimize the occurrence and progression of these lesions (39).

#### **2.1.2.2 Risk factors**

Several factors contribute to the development of WSLs and can be classified into systemic factors and local factors.

### 2.1.2.2.1 Systemic factors

Systemic factors refer to patient-specific characteristics that influence susceptibility to WSLs, regardless of the quality of orthodontic care.

One of the most significant factors is host susceptibility. Not all individuals are equally prone to dental caries: while some develop WSLs despite maintaining seemingly good oral hygiene, others with poorer hygiene may remain unaffected. Enamel lesions can progress from an initial demineralization phase to non-cavitated carious lesions and, ultimately, cavitated lesions. This variability is explained by the multifactorial nature of caries risk, which includes salivary, microbial, dietary, structural, and demographic influences (24).

As previously discussed, saliva plays a crucial role in protecting enamel against demineralization. An abundant and high-quality saliva facilitates the mechanical removal of food debris and bacteria, maintains a neutral or slightly basic pH by neutralizing acids produced by dental biofilm, and supports enamel remineralization through calcium and phosphate ions. Consequently, reduced saliva production or a low buffering capacity significantly increases the risk of WSLs (14).

The oral microbiome is also a major contributor to the development of WSLs. These lesions are closely associated with an increased presence of cariogenic bacteria, particularly *Streptococcus mutans* and *Lactobacillus*. These microorganisms metabolize fermentable sugars present in the oral cavity, producing acids that accelerate enamel demineralization (14,41). At the same time, the composition and structural integrity of the enamel play a crucial role in its resistance to acid attacks. Individuals with highly mineralized and dense enamel are generally more resistant to demineralization, whereas those with porous or hypomineralized enamel are more susceptible to WSLs formation (39).

Diet is another important determinant. A carbohydrate-rich diet (particularly frequent consumption of sugary beverages) exposes enamel to repeated acidification episodes, reducing the time available for natural remineralization through saliva (39). Over time, this imbalance leads to a gradual loss of minerals, weakening enamel and increasing

WSLs risk. The higher the frequency of sugar intake, the greater the risk of demineralization. This underscores the importance of dietary habits in the development of WSLs during orthodontic treatment (14,42).

Finally, demographic factors such as sex and age have been shown to influence WSLs prevalence. Several studies in the scientific literature have highlighted sex-related differences in the prevalence and severity of WSLs among orthodontic patients. Most studies indicate that males exhibit a higher incidence and severity of WSLs compared to females. This discrepancy is primarily attributed to differences in oral hygiene habits, with females generally demonstrating greater commitment to maintaining oral hygiene. They tend to brush their teeth more frequently and meticulously, thereby reducing the risk of enamel demineralization and subsequent WSLs development (14,43–46).

In addition, adolescents under the age of 18 are particularly susceptible to WSLs. This increased vulnerability can be attributed to several factors. Firstly, oral hygiene tends to be less rigorous in this population, with lower adherence to recommended brushing techniques compared to adults. Secondly, dietary habits typical of adolescence, characterized by a higher intake of sugary foods and beverages, represent an additional risk factor, as previously mentioned, further promoting the development of WSLs (43,47). Finally, newly erupted permanent teeth exhibit a lower degree of tissue mineralization, making them more susceptible to demineralization processes that lead to both WSLs and dental caries (6).

#### **2.1.2.2.2 Local factors**

Local factors are directly related to the specific conditions of the patient's oral cavity as well as the presence of orthodontic appliances. First, dental malposition creates areas of plaque accumulation and retention, thereby promoting the development of WSLs (39).

The type of orthodontic appliance used also plays a significant role in the occurrence of WSLs. As previously mentioned, the prevalence of these lesions is higher in patients treated with fixed appliances compared to those using aligners. Fixed appliances, such as brackets, bands, and archwires, promote increased plaque retention, thereby raising the risk of enamel demineralization and, consequently, the formation of WSLs (39). In the

context of aligner therapy, the presence of attachments can also create areas of plaque stagnation. These attachments are geometric shapes made of composite resin, bonded directly to the teeth. Their purpose is to increase the friction between the aligners and the teeth, thereby optimizing the transmission of orthodontic forces. Nevertheless, despite the presence of these elements, aligners, as removable appliances, generally allow for better control of oral hygiene and improved periodontal health. As a result, they may help reduce the development of WSLs compared to fixed appliances (4). Therefore, the type of appliance has a direct impact on biofilm accumulation and the occurrence of WSLs, a topic that will be further explored in the following section.

Moreover, the duration of orthodontic treatment constitutes a risk factor, as prolonged treatment increases plaque accumulation on enamel surfaces, thereby elevating the risk of WSLs. These lesions can appear as early as four weeks after the initiation of orthodontic treatment (24,46). Their prevalence rises significantly during the first six months of treatment, continuing to increase at a slower rate up to 12 months (48).

Finally, the presence of pre-existing WSLs prior to orthodontic treatment is also recognized as a risk factor, predisposing patients to the development of additional lesions during treatment (43).

## **2.2 Orthodontics**

### **2.2.1 Objective of orthodontic treatment**

Orthodontics has long been driven by the pursuit of an ideal occlusion, based on the principles established by Edward H. Angle, and later refined by authors such as Ronald H. Roth and others over time (49). However, the advancement of scientific knowledge and clinical approaches has gradually led to a reassessment of therapeutic goals. Today, the focus is no longer exclusively on dento-skeletal structures, but increasingly on the soft tissues, which are now recognized as key elements in achieving facial balance and long-term treatment stability. This shift in perspective has given rise to the soft tissue paradigm, which posits that facial harmony depends not only on dental alignment and skeletal structures, but also on the functional and aesthetic relationships between these structures and the overlying soft tissues (50).

Facial aesthetics are determined by three main factors: tooth position, skeletal architecture, and soft tissue characteristics (50). Therefore, any orthodontic treatment aiming for aesthetic harmony must take into account the influence of tooth and jaw positioning on soft tissue anatomy. This approach has become a central component of orthodontic diagnosis, treatment planning, and the assessment of aesthetic outcomes. Indeed, soft tissues do not merely cover the dento-skeletal: they interact with it and directly influence the appearance of the face (51). In this sense, modern orthodontics is no longer limited to the correction of malocclusions, but aims for a comprehensive balance that is functional, aesthetic, and sustainable (1).

The integration of soft tissues into treatment planning not only enhances facial aesthetics but also contributes to better adaptation and increased stability of the results achieved (1). While dental occlusion remains a central element of orthodontic treatment, it is not always the primary objective. In certain situations, therapeutic compromises are necessary, such as extractions or dental arch adjustments, to ensure an outcome that is both harmonious, functional, and long-lasting outcome.

Today, the main goals of orthodontic treatment include:

- Facial aesthetics,
- Dental aesthetics,
- Functional occlusion,
- Temporomandibular joint (TMJ) health,
- Periodontal health,
- Long-term stability of results to prevent post-treatment relapse (3).

Additional complementary objectives may also be considered, depending on the clinical context and the patient's expectations.

Nevertheless, it is often impossible to optimize all these objectives simultaneously. For instance, striving for a perfectly ideal occlusion without considering extractions may compromise facial aesthetic balance and long-term stability. Conversely, prioritizing stability might result in a slightly imperfect occlusion or a less optimal aesthetic outcome. Therefore, an individualized and prioritized approach is essential, one that is based on the specific needs and expectations of each patient (52).

Moreover, the patient's psychosocial well-being plays a key role in the decision to undergo orthodontic treatment. Improving the appearance of the smile and the overall facial profile can enhance self-esteem and quality of life, making it a therapeutic objective in its own right (53).

Before initiating any treatment, it is crucial to ensure that the patient's general and oral health is compatible with the planned interventions. This involves the careful management of preexisting conditions, including (1):

- Assessment of systemic medical conditions that may influence the response to treatment (1).
- Prior treatment of dental caries and pulpal pathologies (1).
- Control of periodontal disease, as active periodontitis may compromise treatment stability (54).

Periodontal evaluation holds particular importance. The presence of active periodontal disease is a formal contraindication to any orthodontic intervention. Special

attention should also be given to potential mucogingival issues that could worsen during treatment (6).

Finally, orthodontic treatment planning must follow a rigorous and gradual approach, ranging from the precise identification of imbalances to the development of a personalized treatment plan. This approach helps optimize outcomes by balancing biological imperatives, patient expectations, and technical constraints (1).

## **2.2.2 Description of orthodontic appliances**

### **2.2.2.1 Fixed appliances**

Fixed orthodontic appliances remain one of the most commonly used modalities in orthodontic treatment. They are composed of a variety of materials, both metallic (such as stainless steel, nickel-titanium, and beta-titanium) and non-metallic (such as ceramic, plastic, and hybrid ceramic resins), each offering specific mechanical, aesthetic, and biological properties. The choice of material depends on several factors, including clinical objectives, the patient's aesthetic preferences, and the biomechanical requirements of each clinical case (55).

These appliances are designed to achieve precise tooth movements while ensuring adequate patient comfort and ease of use for the practitioner. A fixed appliance typically consists of three main components: brackets, orthodontic wires (or archwires), and ligatures. Additional accessories may be used depending on the specific requirements of the treatment (55).

#### **2.2.2.1.1 Labial and lingual brackets**

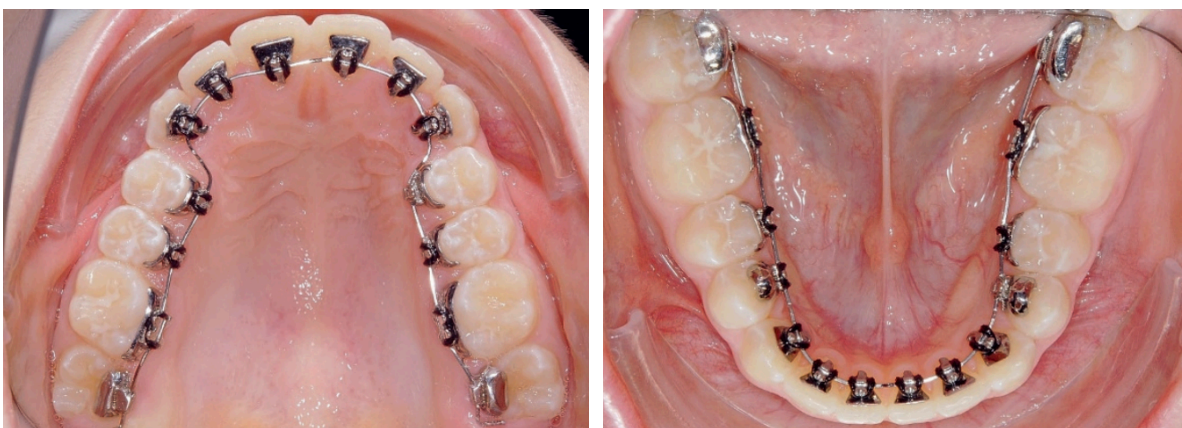
Brackets are small attachments bonded to the labial (outer) or lingual (inner) surfaces of the teeth using adhesive resins. The most commonly used types are stainless steel or titanium and ceramic brackets, which together account for approximately 94% of all brackets: 82% metallic and 12% ceramic (56). Each bracket features a slot designed to accommodate the orthodontic wire, and its geometry directly influences the direction, magnitude, and accuracy of the forces applied. Modern brackets are usually pre-adjusted

with specific angulations (tip and torque), allowing for precise three-dimensional control of tooth movement (57).



**Figure 10.** Photographic adaptation of ceramic brackets on the maxillary teeth and metal brackets on the mandibular teeth. Courtesy of François Durand Pereira.

Lingual brackets, bonded to the inner surfaces of the teeth, provide a highly discreet treatment option that appeals especially to aesthetically conscious patients. As they are completely hidden from view, they serve as an effective alternative to conventional labial systems, although their application requires greater technical precision and clinical expertise (58).



**Figure 11.** Photographic adaptation of lingual brackets (adapted from Graber et al., 2023).

### **2.2.2.1.2 Archwires**

Archwires connect the brackets and serve as the active component of the system, transmitting the forces necessary to induce tooth movement. They are primarily made of stainless steel or nickel-titanium (NiTi) (59).

- NiTi wires, known for their flexibility and shape memory, are typically used in the early stages of treatment to deliver light, continuous forces.
- Stainless steel wires, which are more rigid, are generally used in the finishing stages, where greater precision and control over tooth movement are required (59).

Each material has specific properties in terms of stiffness, elasticity, and resilience, which directly influence the nature and magnitude of the applied forces (58,60).

### **2.2.2.1.3 Ligatures and accessories**

Ligatures are used to secure the archwire within the slot of each bracket. They can be either (60):

- Elastomeric (in the form of colored or transparent rings), or
- Metallic, often used when enhanced control is required.

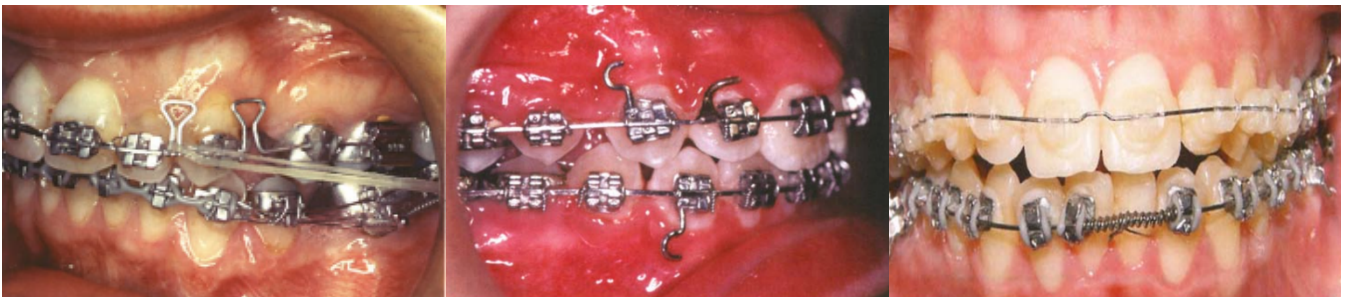


**Figure 12.** Blue elastomeric ligatures on the maxillary teeth, and an alternation of elastomeric and metallic ligatures on the mandibular teeth. Courtesy of François Durand Pereira.

Some brackets, known as self-ligating brackets, are equipped with an integrated closure mechanism that eliminates the need for external ligatures. This design helps to reduce friction between the wire and the bracket, facilitates archwire placement, and, in certain cases, may contribute to a shorter overall treatment duration (60).

In addition to brackets and archwires, auxiliary components can be incorporated into fixed appliances to apply targeted forces for specific tooth movements. These include:

- Intermaxillary elastics, used to correct sagittal discrepancies between the jaws.
- Hooks, which serve as anchorage or attachment points for elastics or other auxiliaries.
- Springs, which exert continuous forces to promote tooth alignment or space closure (60).



**Figure 13.** Photographic adaptation of intermaxillary elastics, hooks, and springs attached to metallic brackets (adapted from Proffit et al., 2018).

Fixed orthodontic appliances function by delivering light, continuous, and controlled forces to the teeth, leading to their gradual displacement within the alveolar bone. As it undergoes deformation, the archwire transmits these forces to the brackets, which subsequently redistribute them to the teeth in accordance with the planned movement direction. The interaction between brackets, archwire, and ligatures constitutes the biomechanical foundation of orthodontic tooth movement (58,60).

#### 2.2.2.2 Clear aligners

Clear aligners have emerged as a contemporary and aesthetically discreet alternative to conventional fixed orthodontic appliances. These removable devices, custom-fabricated for each patient, facilitate the gradual movement of teeth through a series of

thermoformed plastic trays. Each aligner delivers gentle yet precisely calibrated forces, guiding the teeth according to a pre-planned sequence. Their increasing popularity is largely due to several advantages: aesthetic discretion, enhanced comfort during daily use, and greater ease in maintaining oral hygiene compared to traditional fixed appliances (61).

The idea of using transparent trays for orthodontic treatment dates back to 1945. At that time, American orthodontist Harold Dean Kesling proposed a groundbreaking concept: manually repositioning the teeth on a plaster model and then fabricating a series of thermoformed trays, each corresponding to a specific stage of the treatment (62). Although revolutionary, this method remained manual and was limited to minor corrections.

It was only in the late 1990s, with advancements in digital technologies, particularly 3D imaging, digital modeling, and computer-aided manufacturing, that this concept could be industrialized. In 1997, Align Technology launched the first commercial sequential aligner system under the brand name Invisalign®, marking a major turning point in contemporary orthodontic practice (63).

Modern aligner therapy is based on three fundamental technological pillars (62):

- Aligners: a series of custom, successive trays designed to produce gradual tooth movement.
- Composite attachments: small resin elements bonded to the teeth to optimize movement control.
- Treatment planning software: digital tools that simulate and adjust the treatment sequence at each stage.

The aligners fully cover the teeth and are made from thermoplastic materials specially engineered to combine flexibility and rigidity: flexible enough to adapt precisely to the dental anatomy, yet rigid enough to apply effective forces without undergoing deformation (6,58).



**Figure 14.** Photographic adaptation of an aligner (adapted from Proffit et al., 2018).

Attachments are small composite resin elements temporarily bonded to specific teeth (6). They play a crucial role in optimizing aligner treatment by enhancing anchorage and enabling more precise control of the forces applied. Their presence allows for the execution of more complex tooth movements, such as rotations, intrusions, or root tilting, with greater efficiency.



**Figure 15.** Photographic adaptation of an aligner with attachments (adapted from Proffit et al., 2018).

In certain cases, particularly when correcting intermaxillary relationships, the use of intermaxillary elastics is necessary. These elastics, attached to the aligners through specific cutouts (known as precision cuts), help guide and control the relationship between the upper and lower dental arches. Nevertheless, the use of bonded buttons is sometimes necessary (62).

Digital treatment planning, made possible through specialized software, allows practitioners to anticipate the different stages of tooth movement, simulate treatment outcomes, and adjust the therapeutic strategy dynamically as needed (62).

Despite their many advantages, clear aligners have some limitations. Their effectiveness relies heavily on patient compliance, as they must be worn continuously, ideally for 20 to 22 hours a day. The overall duration of treatment typically ranges from 1 to 3 years, although it is often shorter than that required for fixed appliances (6,64).

The decision between using aligners or fixed appliances is based on several factors: the complexity of the clinical case, aesthetic concerns, case difficulty, the patient's level of compliance, and personal preferences (65).

The introduction of an orthodontic device, whether fixed or removable, can disrupt the natural balance of the oral microbiome. The prolonged presence of these biomaterials in the oral cavity may lead to dysbiosis, a microbial imbalance that can favor the development of various oral pathologies (66). This is particularly relevant in the context of early carious lesions, known as WSLs, which are frequently observed during orthodontic treatment. Given their prevalence, it is essential to evaluate and compare the effects of fixed appliances and aligners on oral health, and to identify the specific risk factors associated with each therapeutic modality (67). The following section examines in detail the role of fixed appliances in the development of WSLs.

### **2.2.3 Impact of fixed appliances on the development of WSLs**

Fixed orthodontic appliances, widely used for the correction of malocclusions, are nevertheless associated with several side effects, most notably WSLs, which result from enamel demineralization (66,68,69). These lesions can emerge within the first few weeks of treatment and may persist after appliance removal (68).

This demineralization is largely attributed to alterations in the oral microbiome induced by fixed appliances. Two main mechanisms are involved (66):

- increased dental plaque accumulation, due to the complexity of the appliance structure, and
- impaired oral hygiene, resulting from restricted access to certain areas.

Additional contributing factors include dietary habits, individual host susceptibility, and specific medical conditions (6).

### **2.2.3.1 Dental plaque accumulation**

Fixed orthodontic appliances cover a large surface area of the teeth, and the presence of brackets, archwires, ligatures, and other accessories reduces the effectiveness of toothbrushing, thereby complicating the maintenance of good oral hygiene (66,69). These components increase the surface roughness of dental surface, facilitating bacterial adhesion and establishing conditions favorable for biofilm development, which is difficult to eliminate through mechanical means such as brushing or mastication (6,66,70).

Areas located between the gingival margin and the bracket, as well as underneath archwires, are particularly susceptible to the accumulation of bacterial plaque and the development of WSLs (68). Furthermore, the shape and size of the brackets also influence these processes: simpler and smaller bracket designs are generally preferred, as they tend to reduce bacterial adhesion (70).

However, poor oral hygiene can extend the duration of treatment, compromise therapeutic outcomes, and, in severe cases, lead to irreversible damage to oral tissues. Therefore, maintaining optimal oral hygiene is essential, and patient cooperation plays a critical role in the success of orthodontic treatment (69).



**Figure 16.** Photographic illustration of heavy plaque accumulation associated with fixed orthodontic appliances. Courtesy of François Durand Pereira.

### 2.2.3.2 Influence on the oral microbiome

The accumulation of dental plaque leads to both quantitative and qualitative changes in the oral microbiome. This disrupts the microbial balance that is essential for maintaining oral health, resulting in dysbiosis, a state associated with an increased risk of oral diseases (66). Even when patients improve their oral hygiene habits, significant alterations in the composition of the oral microbiome have been observed in individuals wearing fixed orthodontic appliances (69).

This disruption of the oral ecosystem creates a favorable environment for the proliferation of specific pathogenic bacteria (69). Among these, acidogenic bacteria such as *Streptococcus mutans* play a central role in the demineralization process (68). These bacteria produce acids that diffuse through the enamel, initiating subsurface demineralization. This process persists as long as the conditions remain favorable to their growth (68).

At the microbial level, a significant increase in the presence of *Streptococcus mutans* and *Lactobacillus*, two species strongly associated with caries and the formation of WSLs has been documented in multiple clinical studies involving patients with fixed appliances (65,66,69,71–73).

*Streptococcus mutans* is considered a key pathogen in the development of both dental caries and WSLs (68,72). One study reported a significant increase in its levels over the course of 18 months of orthodontic treatment with conventional brackets (66,72). It was detected in all patients wearing multibracket systems, regardless of their oral hygiene quality (73). Similarly, *Lactobacillus* species were found in all patients, with higher concentrations in those exhibiting poor hygiene and WSLs (66).

In addition to acidogenic bacteria such as *Streptococcus mutans* and *Lactobacillus*, other microorganisms, including *Candida albicans*, also appear to contribute to enamel demineralization. Studies have shown that *Candida* species, particularly *Candida albicans*, are frequently isolated from patients with fixed orthodontic appliances. Their prevalence is significantly higher among individuals with poor oral hygiene and visible WSLs (73). *Candida albicans* is not only consistently detected in plaque associated with WSLs, but it is also enriched in these pathological areas. One study reported that 45% of

patients with WSLs were carriers of *Candida albicans* (74). Thus, patients with WSLs generally exhibit higher microbial loads of *Streptococcus mutans*, *Lactobacillus*, and *Candida* compared to individuals with good oral hygiene (73).

This bacterial overgrowth is accompanied by increased acid metabolism, resulting in a localized decrease in pH within the oral cavity. Such acidification disrupts the solubility equilibrium of hydroxyapatite, the principal mineral component of enamel, leading to its progressive dissolution. These mechanisms are now well established as key contributors to enamel demineralization (6).

### 2.2.3.3 Conclusion

As previously (see *section 2.1.2.1 Prevalence*), the prevalence of WSLs in patients undergoing fixed orthodontic treatment varies across studies but is consistently reported as high. These lesions occur more frequently in patients wearing fixed appliances compared to those using clear aligners. They can develop rapidly, sometimes as early as the first four weeks of treatment (73). In many cases, these lesions become irreversible and appear around brackets at the end of treatment, thereby compromising the aesthetic goals of orthodontic therapy (69).

Moreover, the roughness of orthodontic materials promotes biofilm adhesion, particularly of *Streptococcus mutans*, with colonization increasing over time. This persistent microbial presence contributes to a progressive rise in the risk of dental caries, especially as treatment duration lengthens. This suggests that prolonged treatment is a significant risk factor in the development of carious lesions.

In summary, fixed orthodontic appliances, by making oral hygiene more difficult and promoting plaque accumulation, significantly disrupt the balance of the oral ecosystem. They actively contribute to the proliferation of cariogenic bacteria such as *Streptococcus mutans* and *Lactobacillus*, as well as to the emergence of opportunistic pathogens like *Candida albicans*. This microbial imbalance leads to progressive enamel demineralization and the formation of WSLs, common and undesirable complications of orthodontic treatment (66,68,69).

#### **2.2.3.4 Labial vs. Lingual fixed appliances**

The prevalence of WSLs varies considerably across studies, depending on the detection methods used, the duration of treatment, and the type of orthodontic appliance. However, the scientific literature consistently indicates that lingual orthodontic appliances are associated with a significantly lower risk of WSLs development compared to conventional labial appliances (13,75–77).

Several studies have reported a markedly lower incidence of WSLs when brackets are bonded to the lingual surfaces of teeth. Both the frequency and the severity of the lesions appear to be reduced. Clinically, little to no formation of WSLs has been observed on the lingual surfaces following bracket removal, whether in the maxillary or mandibular arches (13). When lesions are present, their severity on the lingual side is estimated to be up to ten times lower than on the labial side (75).

This phenomenon can be largely explained by the critical role of the salivary environment in preventing enamel demineralization, as discussed in *section 2.1.1.6.2 (The Importance of Saliva in Enamel Remineralization)* of this thesis. The lingual positioning of brackets allows for continuous and direct exposure to saliva (77). This enhanced salivary flow plays a key protective role by diluting acids produced by bacterial plaque, buffering pH changes, and supplying essential ions for enamel remineralization (76). As a result, plaque accumulation is limited, and the risk of acidogenic biofilm formation, the primary etiological factor in WSLs development, is significantly reduced.

These findings suggest that lingual orthodontic appliances may represent a particularly advantageous option in cases where caries risk is elevated, or when the preservation of enamel integrity is a primary therapeutic objective (77).

## **2.2.4 Impact of clear aligners on the development of WSLs**

As previously said, clear aligners have emerged as an increasingly popular treatment option in orthodontics, offering an aesthetic and functional alternative to conventional fixed appliances. Their perceived advantages, such as enhanced aesthetics, greater comfort, ease of use, and potentially shorter treatment duration, have contributed to their growing acceptance and have helped shape patient expectations. Moreover, aligners are often associated with improved oral hygiene due to their removability, which facilitates more effective tooth brushing compared to fixed appliances (4,64).

However, despite this easier access to oral hygiene measures, several studies have reported the persistence, and even the formation, of new WSLs in patients treated with clear aligners. This apparent paradox may be partly explained by the “full coverage” design of the aligners, which creates a closed environment that can promote plaque stagnation and enamel demineralization, especially in the presence of attachments or when the aligners are worn for extended periods without proper hygiene (4). Furthermore, concerns remain regarding the potential impact of aligners on the oral microbiome and periodontal health (6). Thus, although aligners generally allow for better hygiene management than fixed appliances, they do not eliminate the risk of caries or the formation of WSLs.

### **2.2.4.1 Dental plaque accumulation**

Studies consistently show that clear aligners have a generally favorable effect on dental plaque control. Their removable nature allows easier access to tooth surfaces during brushing, thereby promoting better oral hygiene compared to fixed orthodontic appliances (4,6,64,65). Several studies have demonstrated a significant reduction in both the plaque index (PI) and gingival index (GI) among patients treated with aligners (64,67,78).

However, these benefits must be interpreted with caution when considering the microbiological aspects. Although aligners are removed during meals and oral hygiene routines, they are typically worn for approximately 22 hours per day, creating a closed

environment that favors salivary stagnation. This prolonged coverage limits salivary flow and disrupts the natural self-cleansing mechanisms provided by orofacial soft tissues (79).

When saliva becomes trapped beneath the aligners, its protective functions are compromised. The saliva's buffering capacity, self-cleaning mechanism, and remineralization potential are all reduced, which in turn increases the risk of gingival irritation and enamel demineralization (4,7,79). In addition, aligners are not entirely smooth. The internal surfaces, subject to wear, porosity, and the formation of microcracks and scratches, provide an ideal substrate for bacterial adhesion and biofilm development (4,78).

Another important factor contributing to plaque formation during aligner therapy is the presence of attachments, small composite resin projections bonded to selected teeth and hardened using light polymerization, to facilitate specific tooth movements. Although discreet and anatomically contoured, attachments create additional areas that retain plaque, particularly at angles, surface irregularities, and the resin–enamel interface (79,80). Their presence can complicate oral hygiene maintenance, especially when attachments are numerous or positioned in areas that are difficult to clean effectively. Notably, patients with a greater number of anterior attachments have been observed to develop significantly more WSLs, suggesting that attachments may represent a localized risk factor (6). Furthermore, during their placement, excess resin is frequently left around the attachments. This residual adhesive is often difficult to remove completely, and its irregular borders provide further sites for bacterial colonization (6). Conversely, an insufficient amount of adhesive material during the placement of attachments may compromise their adaptation to the enamel surface. This lack of optimal sealing at the resin–enamel interface can lead to the formation of subgingival microgaps, which promote bacterial infiltration and plaque stagnation. These areas, often invisible and difficult to access with conventional oral hygiene tools, represent an additional localized risk factor for the development of WSLs. Thus, although clear aligners generally facilitate better oral hygiene compared to conventional fixed appliances, the presence of attachments can locally diminish these advantages by creating niches favorable to biofilm accumulation, enamel demineralization, and ultimately the formation of WSLs (4,80).

Additionally, the near-complete coverage of the dental crowns by the aligners creates a sealed environment around the tooth surfaces. Without regular and thorough cleaning of the aligners themselves, this confined space can become harmful to enamel health, by promoting plaque and acid accumulation (4).

#### **2.2.4.2 Influence on the oral microbiome**

Clear aligners, due to their nearly complete coverage of dental surfaces and their extended daily wear time, create an environment conducive to alterations in the oral microbial ecology. Their use has been shown to affect the abundance, diversity, and metabolic composition of the oral microbiota, while also modifying the structure of both supra- and subgingival biofilms. This ecological imbalance may promote the development of cariogenic bacterial species (6).

Several studies have first reported a decrease in microbial diversity within plaque samples collected from aligner wearers, along with an increased prevalence of *Streptococcus mutans*, *Granulicatella* spp., and *Lactobacillus* spp., all microorganisms implicated in WSLs and caries development (4,7,78). This alteration appears to be multifactorial. On the one hand, plaque accumulation on the inner surfaces of aligners is facilitated by the infiltration of saliva into the microspaces between the aligners and the teeth (4). On the other hand, the continuous presence of aligners limits salivary flow to certain dental areas, thereby reducing the natural cleansing action of saliva and encouraging plaque stagnation, an essential factor in enamel demineralisation and the formation of WSLs (6).

The resulting biofilm on the aligners tends to display a distinct bacterial profile, characterized by reduced diversity and an enrichment in cariogenic pathogens. This dysbiosis may also be partially explained by the affinity of certain bacterial species for the thermoplastic materials used in aligner fabrication (4).

However, several studies have highlighted that the microbiological imbalance associated with clear aligners is significantly less pronounced than that observed with fixed orthodontic appliances, particularly regarding the protective commensal species. Among patients treated with aligners, salivary concentrations of *Streptococcus mutans*

and *Lactobacillus* are significantly lower than those observed in individuals wearing fixed appliances (4,65,78).

For instance, in the study by Oikonomou et al. (2021), a significant reduction in the detection of cariogenic bacteria was observed between 3 and 6 months after the beginning of treatment in patients undergoing aligner therapy, compared to those with fixed appliances. Specifically, patients in the aligner group showed a reduction in *Streptococcus mutans* levels ranging from 74% to 93%, and in *Lactobacillus spp.* from 81% to 91%, relative to the fixed appliance group (64).

These findings suggest that, in the early stages of treatment with clear aligners, the salivary microbiome maintains a relatively stable structure without a notable increase in cariogenic species. However, it remains to be determined whether this microbial balance persists over the long term. Nevertheless, the initial phase of aligner therapy may be marked by a transient dysbiosis, a phenomenon frequently observed following the insertion of any foreign object into the oral cavity (67).

#### **2.2.4.3 Conclusion**

In conclusion, regarding the impact of clear aligners on the development of WSLs, multiple studies have confirmed that their prevalence is significantly lower in patients treated with clear aligner therapy (4).

This observation can be primarily attributed to the removability of aligners, which allows for more effective oral hygiene, as well as to shorter overall treatment durations (4,79) and a reported reduction in the frequency of food intake among study participants (7). However, WSLs are not entirely absent in patients undergoing aligner therapy. Their occurrence is typically associated with poor oral hygiene, frequent consumption of sugary or acidic beverages, or the presence of attachments, which act as plaque-retentive areas. Indeed, many patients consume acidic or sugary drinks such as sodas while wearing their aligners, which facilitates the entrapment of these substances beneath the trays (79). Such individuals are more likely to develop WSLs due to poor compliance and risky dietary behaviors (6,64).

There is also some evidence suggesting that orthodontic treatment with aligners may have beneficial effects, at least in the short term, particularly in adult patients (6,64). In contrast, adolescents often neglect to clean their aligners properly after meals, leading to plaque accumulation along the incisal edges of anterior teeth, around attachment sites, and on the palatal surfaces of posterior teeth, areas where WSLs do not typically appear during treatment with fixed appliances, as previously mentioned (6).

In summary, clear aligners offer certain preventive advantages over fixed appliances regarding orthodontic-related oral pathologies. These include reduced plaque accumulation, better preservation of oral microbiota stability, and a lower risk of developing WSLs. However, these benefits are highly dependent on rigorous oral hygiene practices and strong patient compliance (80). In the absence of these conditions, aligners may themselves become a risk factor, due to saliva stagnation, material porosity, and the presence of attachments. Therefore, patient education and regular follow-up are essential to maximize the therapeutic benefits of aligners while minimizing their potential adverse effects.

#### **2.2.4.4 Limitations**

Although clear aligners are generally associated with improved oral hygiene compared to fixed appliances, their use still presents certain limitations, both clinically and scientifically. Due to their relatively recent introduction, data regarding their potential side effects, particularly the development of WSLs, remain limited. Few studies have investigated the incidence and severity of these lesions, and those available often suffer from methodological heterogeneity, small sample sizes, and the absence of standardized diagnostic protocols. For instance, some investigations rely solely on photographic analysis, without the use of more sensitive techniques such as QLF, which may lead to an underestimation of both the prevalence and severity of these lesions (6,64).

Moreover, several systematic reviews have highlighted the overall low quality of the available evidence (64). This limitation stems from the small number of studies, the significant variability in methodological approaches, particularly in the analysis of the oral microbiome, and the lack of long-term follow-up (67). Another often-overlooked

issue concerns the lack of detail regarding the specific characteristics of the aligners used, such as the presence or absence of attachments, which can nevertheless influence plaque accumulation (67).

In summary, while clear aligners offer undeniable advantages, especially in terms of aesthetics and oral hygiene, current knowledge does not yet allow us to rule out the possibility of long-term adverse effects. Further well-designed studies involving larger cohorts are required to better understand their impact on oral health and to identify associated risk factors.

### **2.2.5 Conclusion of fixed Appliances vs. Clear aligners and the occurrence of WSLs**

In conclusion, orthodontic treatments, whether performed with fixed appliances or clear aligners, can disrupt the oral microbiota and potentially lead to dysbiosis (67). However, the mechanisms involved and the severity of WSLs vary significantly depending on the type of appliance used.

Fixed multibracket appliances create a structurally favorable environment for plaque accumulation due to the presence of brackets, wires, ligatures and accessories. These components increase the surface roughness of teeth and hinder the maintenance of optimal oral hygiene. As a result, there is a notable proliferation of acidogenic bacteria (such as *Streptococcus mutans* and *Lactobacillus*) and fungal organisms (*Candida albicans*), which substantially increases the risk of developing WSLs.



**Figure 17.** Right, frontal, and left intraoral views following debonding of orthodontic brackets. WSLs are visible around former bracket sites. Courtesy of François Durand Pereira.

In contrast, clear aligners, although they also disturb microbial balance, offer improved hygiene control thanks to their removability. They are generally associated with a lower overall incidence of WSLs and better microbiological stability. Nevertheless, aligners present specific challenges, such as a closed environment that limits the protective actions of saliva and the presence of attachments that can retain plaque. These factors may also lead to WSLs if patient hygiene and behavior are suboptimal. Thus, their effectiveness heavily depends on patient compliance: extended wear without removal for meals or brushing, irregular cleaning of the trays, or the consumption of sugary drinks while wearing aligners can negate their advantages. Further research is needed to fully understand the long-term effects of aligners on oral health (64).

Although the incidence of WSLs is generally higher in patients treated with fixed appliances, several recent studies suggest that the extent of the lesions may be greater in those using clear aligners (64,67,80). Indeed, studies have shown that in patients with fixed appliances, WSLs tend to appear as localized spots, primarily around the brackets (67). This distribution is explained by plaque accumulation in the retention zones created by brackets and wires. On the other hand, in patients treated with aligners, lesions tend to be more diffuse, covering a broader enamel surface. This distribution pattern may be due to the prolonged coverage of dental surfaces by the aligners, which limits exposure to saliva and its protective effects (buffering capacity, self-cleaning, and remineralization). In fact, patients using aligners have been shown to exhibit significantly larger areas of decalcification compared to those treated with fixed appliances (64).

However, although these lesions may be more extensive, their demineralization depth is generally lower than in patients with fixed appliances. One study reported an average mineral loss of 0.4% in the aligner group versus 1.2% in the fixed appliance group. This increased mineral loss in the latter is attributed to greater plaque accumulation, which is exacerbated by the surface roughness of orthodontic materials and the difficulty of maintaining effective brushing (80).

Moreover, the distribution of WSLs varies significantly depending on the type of orthodontic appliance used. With clear aligners, plaque accumulation is frequently observed, promoting the development of WSLs particularly in the anterior regions, around attachment sites, and on the palatal surfaces of posterior teeth, locations that are

relatively uncommon with other types of appliances (6). In contrast, vestibular fixed appliances are more commonly associated with WSLs that develop around and beneath the brackets, especially in the anterior regions and the mandibular posterior area, where plaque control is more challenging, access for brushing is limited, and salivary flow is reduced (13). By comparison, lingual or palatal brackets are associated with a markedly lower incidence and severity of WSLs, likely due to better exposure to salivary flow and reduced plaque retention on the treated surfaces (75,77).

Ultimately, patient education and diligent follow-up remain crucial, regardless of appliance type, to minimize the risk of enamel demineralization and optimize orthodontic treatment outcomes (65).

## 2.2.6 Comparative table of the impact of fixed appliances and aligners on the occurrence of WSLs

**Table 4.** Comparison of the effects of fixed appliances and aligners on oral health and the development of WSLs.

Characteristics	Fixed Appliances	Aligners
Oral hygiene	Difficult to maintain due to brackets, wires, ligatures, and elastics.	Removable, allowing for easier oral hygiene maintenance.
Plaque accumulation	Promoted by retention of food debris and multiple plaque-retentive sites.	Reduced due to removability. However, accumulation may occur under closed trays and around attachments.
Microbiome stability	Significant alteration and dysbiosis.	Relatively more stable compared to fixed appliances.
Colonization by acidogenic bacteria	Increased presence of <i>S. mutans</i> , <i>Lactobacillus</i> spp., and <i>C. albicans</i> .	Lower levels of <i>S. mutans</i> and <i>Lactobacillus</i> spp. Potential alteration under aligner trays.
Presence of <i>Candida Albicans</i>	Frequent.	Rare.
Oral environment	Open but obstructed by appliances, which disrupt natural salivary flow.	Closed environment under trays, limiting salivary circulation and self-cleaning mechanisms.
Saliva function	Less effective for self-cleansing and protective functions around brackets. Lingual appliances allow better salivary access.	Restricted in enclosed spaces beneath the aligners.
WSLs demineralization risk	High and frequent risk. Lesions may be irreversible around brackets.	Significantly lower risk. Lesions may develop due to poor hygiene or acidic/sugary beverages, especially near attachments.
Lesion extent	Localized around brackets.	More diffuse and extended over multiple surfaces.
Demineralization depth	Deeper ( $\approx 1.2\%$ mineral loss).	Shallower ( $\approx 0.4\%$ mineral loss).
Patient compliance required	Moderate.	High.
Aesthetic during treatment	Moderate.	Very high.

## **2.3 Prevention and management of WSLs**

While comparing different orthodontic appliances allows for the identification of specific risk factors, the effective management of WSLs relies primarily on the implementation of rigorous preventive strategies. This section aims to explore the various current approaches available to prevent the onset of WSLs during orthodontic treatment, as well as the methods used to manage these lesions once established, to minimize their clinical and aesthetic impact.

The management of WSLs requires a multifactorial approach. The most crucial strategy is to prevent demineralization and biofilm formation. This begins with patient education and motivation to maintain excellent oral hygiene and adopt a non-cariogenic diet (45). Maintaining good oral hygiene is therefore considered the most important preventive measure for patients undergoing orthodontic treatment, whether using fixed or removable appliances, in order to prevent the development of WSLs (39,45).

### **2.3.1 Prevention of WSLs**

#### **2.3.1.1 Systemic prevention**

##### **2.3.1.1.1 Oral hygiene**

Oral hygiene is crucial and should be carefully assessed both before and throughout the course of orthodontic treatment (81). Manual and electric toothbrushes, as well as interdental brushes, are strongly recommended for patients with fixed (labial and lingual) or removable appliances. Electric toothbrushes may offer superior plaque control compared to manual ones in orthodontic patients (82).

In the specific case of clear aligners, rigorous daily cleaning of the trays is essential to prevent biofilm accumulation, reduce the risk of halitosis, discoloration, and microbial imbalance. Various at-home cleaning methods are available, both mechanical and chemical, each with variable levels of effectiveness (83).

Mechanical methods, such as brushing with a soft-bristled toothbrush, help remove visible deposits. However, they are not always sufficient to eliminate microscopic

biofilm. Thorough brushing remains effective, but the use of abrasive toothpastes can damage the surface of the aligners; therefore, non-abrasive products are generally recommended. Electric toothbrushes, although less studied in this context, have also shown promising results (83). Chemical methods rely on the use of effervescent tablets (commonly based on sodium carbonate and sodium sulfate) or antiseptic solutions, such as diluted chlorhexidine. These agents reduce bacterial load but should ideally be combined with mechanical cleaning for optimal effectiveness (83).

The most widely recommended method involves immersing the aligners in a solution containing a water-soluble tablet, followed by brushing with a soft toothbrush and a non-abrasive toothpaste. This approach combines the benefits of both techniques. Although it does not completely eliminate bacterial residues, it is significantly more effective than rinsing with water alone. In conclusion, current evidence supports the implementation of a combined protocol, integrating gentle mechanical cleaning with regular chemical disinfection. This protocol should be adapted to each patient, considering their motivation, oral hygiene habits, and technical abilities (83).

#### **2.3.1.1.2 Diet**

Dietary measures are a key component of WSL prevention strategies (39). Individualized dietary assessment and counselling help raise patient awareness regarding simple yet effective principles, such as reducing the frequency and duration of exposure to sugary beverages (like sodas, fruit juices, and energy drinks, as well as acidic candies). Meal and snack patterns directly influence the frequency of fermentable carbohydrate intake, thereby increasing the risk of caries.

Although rarely addressed by orthodontists due to time or resource limitations, dietary assessment should be an integral part of preventive care. Excessive consumption of cariogenic foods and drinks constitutes a significant risk factor for the development of WSLs, justifying its inclusion in patient follow-up (39,42).

In addition to traditional dietary interventions, recent studies have highlighted the therapeutic potential of natural substances such as probiotics in modulating microbial

dysbiosis. These innovative biological approaches open the door to more personalized prevention and treatment strategies for WSLs in orthodontic patients (7,45).

In summary, dietary modification, particularly the reduction of sugar and fermentable carbohydrate intake, is a fundamental element in the prevention of WSLs and should be implemented alongside proper oral hygiene practices (39,42,45). Moreover, the complementary use of probiotics and other biological agents may help stabilize the oral microbiome and provide additional protection against WSLs development (7,45).

### **2.3.1.2 Localized prevention**

#### **2.3.1.2.1 Fluoride**

Topical application of fluoride is a key preventive strategy to limit the development of WSLs in patients undergoing orthodontic treatment (45,70).

#### **2.3.1.2.2 Fluoridated toothpastes**

Toothpaste is the most commonly used source of fluoride among orthodontic patients. Therefore, it is recommended that all patients undergoing orthodontic treatment use a fluoride toothpaste containing at least 1000 ppm of fluoride, twice daily. Regular use of toothpaste with fluoride concentrations above 1000 ppm has been shown to reduce the incidence of WSLs (81,84). Moreover, high-fluoride toothpaste (5000 ppm) has proven to be more effective in preventing WSLs formation than conventional fluoride toothpaste (1450 ppm), making it a particularly valuable preventive measure for high-risk patients (70,84).

#### **2.3.1.2.3 Fluoride mouthrinses and gels**

On one hand, daily use of fluoride mouthrinses is a complementary measure recommended for the prevention of WSLs in orthodontic patients (39,70,84). Although specific data for the orthodontic population are limited, several studies conducted in the general population have shown that fluoride mouthrinses provide additional protection against caries, particularly in children, beyond conventional fluoride intake. As a result,

orthodontists frequently recommend the use of an at-home fluoride mouthrinse containing 230 to 250 ppm of fluoride throughout the duration of fixed appliance therapy (84). However, the effectiveness of this approach depends heavily on patient compliance, which often remains suboptimal, with only a minority of patients adhering to these recommendations (39,70).

On the other hand, fluoride gels are more commonly indicated for use with labial and removable appliances (82). Nevertheless, their effectiveness remains debated: some studies have found no significant difference in WSLs prevention following quarterly applications (70). Similarly, evidence regarding the efficacy of fluoride gels or foams, whether applied at home or professionally, remains inconclusive overall (84).

#### **2.3.1.2.4 Fluoride varnishes**

High-concentration fluoride varnishes are a well-established prophylactic measure for reducing the prevalence of WSLs, particularly in patients with suboptimal oral hygiene (10,70,81). Their regular professional application throughout orthodontic treatment can significantly limit enamel demineralization (10,70).

One study reported that a varnish containing 7700 ppm of fluoride in its wet state (approximately 30,000 ppm when dry), applied systematically at each orthodontic adjustment visit, reduced the incidence of WSLs compared to a placebo varnish, with an absolute risk reduction of 18%. However, other studies conducted under similar conditions, however, did not demonstrate a significant effect. (84).

Application frequency is a key factor in maximizing the preventive efficacy of fluoride varnishes. Recommended protocols suggest regular applications every six weeks or at intervals of 3 to 6 months (10,70). Furthermore, clinical trials have shown that a 5% sodium fluoride varnish applied periodically can significantly reduce demineralization of treated anterior teeth compared to untreated controls (10). Nevertheless, this protective effect appears to be less pronounced in patients with rigorous oral hygiene (10,70).

Finally, fluoride varnishes are simple and quick to apply and do not rely on patient compliance, making them a particularly suitable strategy for WSLs prevention in orthodontics, especially for high-risk patients (10,70).

#### **2.3.1.2.5 Fluoride-Releasing materials**

The use of fluoride-releasing bonding materials, such as resin-modified glass ionomer cements (RMGIC), has been proposed as a preventive strategy to limit bacterial proliferation and reduce the risk of WSLs during orthodontic treatment (81). These materials have the ability to release fluoride directly at the enamel surface, where the risk of demineralization is highest. However, several limitations persist. Fluoride release is typically not sustained: it tends to be high initially, then rapidly declines. While conventional glass ionomers have shown some preventive potential, their low mechanical strength often leads to a high rate of bracket debonding. RMGICs, being more resistant, seem to be better tolerated, without an increased rate of bracket failure compared to conventional composites. However, their effectiveness in reducing the incidence of WSLs at the end of treatment remains to be confirmed (84). Moreover, the addition of fluoride to conventional composites does not appear to provide any significant clinical benefit, as the formation of WSLs is comparable to that observed with non-fluoridated composites (81).

Although fluoride-releasing bonding materials hold theoretical interest, current clinical evidence supporting their effectiveness in preventing WSLs remains limited (81,84).

#### **2.3.1.2.6 Products containing Casein Phosphopeptide - Amorphous Calcium Phosphate (CPP-ACP)**

Among the non-invasive approaches proposed for the prevention or treatment of WSLs, products containing CPP-ACP have generated growing interest in the scientific literature (42,45,70). CPP-ACP is a nanostructured complex capable of stabilizing calcium and phosphate ions in a bioavailable form. In the presence of oral acidity, these ions are gradually released, inducing a localized supersaturation in the saliva. This promotes the precipitation of calcium-phosphate minerals onto demineralized enamel

surfaces. Furthermore, CPP-ACP exhibits a high affinity for dental surfaces and bacterial membranes, thereby enhancing its protective potential (42). Its mechanism of action may allow for deeper ion penetration, leading to the remineralization of the entire lesion (45).



**Figure 18.** MI Paste Plus ® (GC America Inc, Alsip, Illinois) is a water-based, sugar-free crème containing Recaldent casein phosphopeptide–amorphous calcium phosphate and fluoride (adapted from Graber et al., 2023).

Recaldent™, the commercial form of CPP-ACP, is available in various formulations, including gum, mouth rinses, and topical pastes such as MI Paste and MI Paste Plus (GC America). Several *in vitro* studies have demonstrated its efficacy in reducing dentinal hypersensitivity, limiting demineralization, and enhancing enamel remineralization. Some studies have also reported that the daily application of a CPP-ACP remineralizing cream significantly reduced the severity and visibility of WSLs that developed following orthodontic treatment, showing greater efficacy than fluoride toothpaste (45). Furthermore, enamel remineralized through topical application of CPP-ACP chewing gum may exhibit greater resistance to subsequent acid attacks compared to remineralization achieved through salivary mechanisms alone (42).

However, despite these promising results, current clinical evidence remains limited. In the absence of large-scale randomized controlled trials, its *in vivo* efficacy cannot be definitively confirmed, and its long-term use in caries prevention cannot yet be systematically recommended (45,70).

#### **2.3.1.2.7 Chlorhexidine**

Chlorhexidine is recognized as one of the most effective antibacterial agents against *Streptococcus mutans* (39). The primary objective of antimicrobial therapy is to modulate the oral biofilm, shifting it from a pathogenic to a more ecologically favorable state. The assessment of salivary *Streptococcus mutans* levels using a semi-quantitative method may serve as a valuable diagnostic tool in determining the need for antimicrobial treatment (42).

The combination of chlorhexidine therapy with fluoride supplementation during fixed orthodontic treatment has demonstrated a protective effect against the development of WSLs. However, prolonged use of chlorhexidine may lead to undesirable side effects, such as altered taste sensation and tooth staining (39). Therefore, chlorhexidine mouth rinses are best suited for use in short-term intensive protocols, particularly in patients with poor compliance regarding conventional oral hygiene measures, to help prevent the occurrence of WSLs (42).

#### **2.3.1.2.8 Sealants**

The application of sealants in patients undergoing fixed orthodontic treatment has proven effective in reducing the incidence of WSLs. However, despite positive clinical outcomes, their long-term durability remains limited. The protective effect of sealants gradually decreases due to mechanical abrasion, particularly from toothbrushing, making reapplication approximately every three and a half months necessary to maintain their preventive efficacy (81).

### **2.3.2 Treatment of WSLs**

Following the removal of orthodontic appliances, spontaneous regression of WSLs is frequently observed, primarily due to the remineralizing effect of saliva and mechanical abrasion from toothbrushing (45,81). This improvement, usually limited to the first six months after debonding, depends largely on the initial depth and extent of the lesions (39,45). However, natural recovery is often incomplete, and many lesions persist, thereby justifying the implementation of targeted treatment (45,81). Management of WSLs relies on a multidimensional approach, incorporating non-invasive techniques such as

remineralization (using fluoride or CPP-ACP), tooth whitening, microabrasion, and resin infiltration. In more advanced cases or those with significant aesthetic concerns, restorative options such as composite resins or veneers may be considered (39,45).

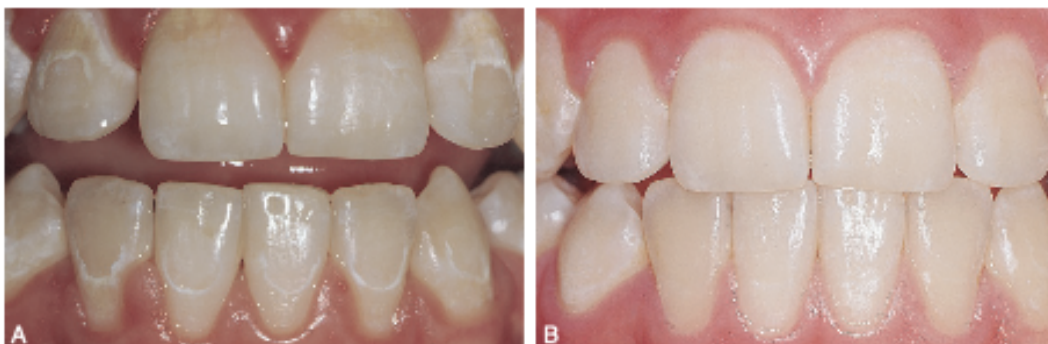
### **2.3.2.1 Remineralization**

Remineralization represents a key strategy in the management of WSLs induced by orthodontic treatment. These lesions, typically superficial and at an early stage, are particularly responsive to remineralizing protocols. The application of agents rich in fluoride, calcium, and phosphate remains the cornerstone of this approach (42). Among the available agents, CPP-ACP complexes have demonstrated the ability to promote deeper remineralization of the lesion. Some studies suggest that regular application of CPP-ACP may be more effective than fluoride mouthrinses in remineralizing post-orthodontic WSLs (45).

Hydroxyapatite, particularly in its nano-hydroxyapatite form, represents a promising approach to remineralization, particularly in high-risk patients. In the study by Bossù et al. (2019), it was demonstrated that toothpastes containing nano-HAP (Biorepair®), when applied daily, can promote the remineralization of WSLs, with results comparable to, or even exceeding, those obtained with traditional fluoride toothpastes (85). Used in a biomimetic approach, this synthetic form of hydroxyapatite is designed to integrate seamlessly into the enamel's crystalline structure, promoting a restoration that closely mimics natural tissues. Thanks to its ability to repair hard dental tissues, it offers protection against wear, erosion, and caries. In addition to its remineralizing properties, nano-hydroxyapatite also acts as an effective desensitizing agent and may be more effective than fluoride. Studies have shown that nano-hydroxyapatite-based toothpaste can significantly reduce dentin hypersensitivity, in some cases more effectively than conventional fluoride toothpaste. Thus, hydroxyapatite may represent an interesting alternative or complementary option to traditional fluoride treatments. If these findings are confirmed, it could progressively become a new standard in the field of remineralization (81).

### **2.3.2.2 Microabrasion**

Microabrasion is an effective technique for reducing superficial WSLs that appear after orthodontic treatment (39,86). This method relies on a combined chemical and mechanical action, using mildly acidic and abrasive agents. Among the most frequently used protocols are 37% phosphoric acid combined with pumice, and 6% hydrochloric acid mixed with silica. The main goal is to remove the superficial layer of demineralized and porous enamel responsible for the aesthetic alteration, while preserving as much healthy tissue as possible (86). This conservative approach enhances the appearance of the smile while remaining minimally invasive (45). Microabrasion is particularly indicated when lesions are confined to the enamel layer (39). It is considered a safe and minimally invasive technique, and can also be combined, when necessary, with tooth bleaching procedures to further optimize aesthetic outcomes (86). Comparable to resin infiltration, microabrasion has shown notable effectiveness in reducing the size and visibility of post-orthodontic WSLs (81). However, due to its slightly more invasive nature, it is often advisable to wait a few months after appliance removal before proceeding, to allow for natural lesion improvement through salivary remineralization and the mechanical abrasion of daily brushing, as mentioned in the previous section. Although this technique can achieve satisfactory aesthetic results, the enamel changes are not always stable over time and may be prone to new extrinsic staining. In cases of deeper demineralization, restorative treatments such as selective enamel reduction or composite restorations may be necessary (56).



**Figure 19.** White spot lesions before (A) and after (B) microabrasion (adapted from Graber et al., 2023).

### 2.3.2.3 Resin infiltration

Resin infiltration is a recent, minimally invasive treatment option for managing WSLs (39). The technique involves infiltrating the lesion with a low-viscosity resin, such as ICON®, after increasing the permeability of the outer enamel surface through acid conditioning. ICON® is a resin based on triethylene glycol dimethacrylate (TEGDMA), a low-viscosity monomer. In its polymerized form, this resin is capable of easily penetrating the porous structure of demineralized enamel. By filling the microporosities within the enamel, it helps stabilize and reinforce the weakened enamel prisms. Moreover, due to its refractive index being close to that of healthy enamel, this technique offers an effective aesthetic masking of WSLs, while also contributing to the reinforcement of the enamel structure. It provides a notable aesthetic advantage over microabrasion, as it more effectively reduces the visibility of WSLs (56). Compared to microabrasion, resin infiltration offers a significant aesthetic benefit by further reducing the visibility of WSLs (81). Studies indicate that resin infiltration outperforms conventional treatments based on fluoride or calcium phosphate in decreasing the visibility of WSLs. It also demonstrates greater initial resistance to staining (56). However, it is important to consider that these results may evolve over time, as the resin can age and discolor, potentially compromising its long-term aesthetic effect (39). This method is appropriate only for lesions caused by enamel demineralization. It is not effective for discolorations resulting from other causes such as fluorosis, developmental enamel defects, or trauma, since these types of lesions lack the necessary porosity for effective resin penetration (56).



**Figure 20.** Resin infiltration provides a minimally invasive treatment approach to transform the outer surface of affected teeth into a more permeable layer with the help of hydrochloric acid (HCl) etching, and infiltrating the porous structure beneath it using a TEGMA-based, low-viscosity resin (adapted from Graber et al., 2023).

#### **2.3.2.4 Bleaching**

Dental bleaching is a viable option to diminish the visibility of WSLs by promoting a more uniform enamel coloration. This technique effectively masks white spots, particularly when natural remineralization proves insufficient. The application of 10% carbamide peroxide has demonstrated efficacy without compromising the structural integrity of the enamel. Furthermore, incorporating CPP-ACP into the treatment can enhance remineralization beneath the lesion's surface. Recent studies also indicate that the inclusion of innovative biomaterials, such as nano-hydroxyapatite, bioactive glass, or amorphous calcium phosphate, within bleaching agents may mitigate adverse effects, including dental sensitivity and enamel hardness reduction. Consequently, bleaching represents a promising approach for patients maintaining good oral hygiene, though it should be employed judiciously to optimize outcomes and minimize risks (39,45).

#### **2.3.2.5 Laser**

Lasers have been increasingly studied for their potential role in preventing and treating WSLs (39,45,70). Since the 1970s, it has been established that lasers can strengthen tooth enamel by altering its structure, making it harder and more resistant to acid attacks responsible for caries formation. Various types of lasers are used in dentistry, including argon, CO<sub>2</sub>, Nd:YAG, and Er:YAG lasers (39,45). For example, argon laser treatment has been shown to reduce enamel demineralization by up to 50% and decrease lesion depth (45). The mechanism involves creating microzones within the enamel that enhance mineral uptake, thereby reinforcing the tooth surface. This technique is particularly valuable for patients at high risk of caries, such as those struggling to maintain good oral hygiene or those wearing orthodontic appliances that promote plaque accumulation.

However, the results of studies on the use of lasers to prevent WSLs in orthodontics are not yet all consistent. Some research reports positive effects, while others find no significant improvement. Therefore, further investigations through well-controlled clinical trials are necessary to better understand their efficacy. In summary, lasers could become a valuable tool to protect enamel and reduce the occurrence of WSLs during orthodontic treatment. Yet, widespread adoption requires more robust scientific evidence confirming these benefits (45).

### **2.3.3 Conclusion**

In conclusion, the prevention WSLs during orthodontic treatment is essential to preserve long-term oral health and aesthetics. Rigorous oral hygiene, combined with the daily use of fluoride-rich toothpastes and mouth rinses, remains the cornerstone of this preventive approach. The regular application of fluoride varnishes and the use of products containing CPP-ACP significantly enhance the remineralization of compromised enamel areas.

The orthodontist plays a pivotal role, not only in prescribing these measures but also in supporting, educating, and motivating patients, thereby fostering their active commitment to maintaining optimal oral hygiene.

When WSLs appear, several treatment options are available depending on lesion severity: non-invasive methods such as topical application of fluoride and CPP-ACP promote remineralization, while more targeted techniques, including resin infiltration and microabrasion, can improve the aesthetic appearance of more visible lesions. Dental bleaching may also be considered to even out enamel coloration, although this approach should be used cautiously due to potential sensitivity risks. Additionally, innovative methods such as laser treatment, while promising in enhancing enamel resistance, require further research to confirm their long-term clinical efficacy.

Finally, despite significant progress in understanding and managing WSLs, some studies report conflicting results. Future research should focus on optimizing treatment protocols, personalizing therapies according to individual patient profiles, and rigorously evaluating the effectiveness and durability of various interventions to improve the overall management of WSLs in orthodontic patients (70).



### III. CONCLUSION

Orthodontic treatment, while primarily aimed at enhancing dental and facial aesthetics and optimizing occlusal relationships, may also lead to unintended side effects on oral health, most notably, the development of WSLs. The prevalence of these enamel lesions increases significantly during treatment, with widely varying rates reported across studies. Whether using fixed appliances or clear aligners, a disruption of the oral ecosystem is frequently observed, promoting oral microbiome dysbiosis, increased plaque accumulation, and progressive enamel demineralization.

Fixed appliances, due to their numerous components (such as brackets, archwires, and ligatures), create plaque-retentive areas that are difficult to clean effectively. This favors the proliferation of cariogenic microorganisms, including *Streptococcus mutans*, *Lactobacillus spp.*, and *Candida albicans*, which are directly implicated in the development of WSLs. However, not all fixed appliance systems are equal in this regard: lingual appliances, which are more directly exposed to saliva, appear to benefit from a more effective natural protective environment.

Clear aligners, being removable and perceived as more aesthetic, allow for better oral hygiene, and are associated with a lower prevalence of WSLs. However, their prolonged wear time creates a closed environment that limits the protective effects of saliva, including self-cleansing, buffering capacity, and remineralization. Moreover, the attachments required for aligner therapy can locally promote plaque accumulation. While WSLs associated with aligners tend to be more diffuse and widespread, they are generally shallower than those seen with fixed appliances. Although aligners offer a relative advantage in preventing WSLs, their effectiveness largely depends on the patient's motivation and compliance with instructions, namely, consistent wear, thorough cleaning of the trays, and strict oral hygiene practices.

In conclusion, although clear aligners are generally associated with a lower overall risk of WSLs, no orthodontic system entirely prevents their occurrence. Prevention remains essential, relying on proper oral hygiene, dietary control, fluoride use, and the active involvement of the patient, supported by their practitioner. The management of WSLs should be individualized, depending on their extent and aesthetic impact.

While current data provide valuable insights into the relationship between orthodontic treatment and WSLs, certain limitations must be acknowledged. Clear aligners, although increasingly used in clinical practice, remain a relatively recent treatment modality compared to fixed appliances. As a result, the literature concerning aligners is still less extensive and often affected by methodological limitations, including small sample sizes, lack of randomization, insufficient follow-up duration, and heterogeneity in the treatment protocols assessed. This limited evidence base makes it challenging to accurately evaluate their long-term impact on the development of WSLs. It is therefore essential to pursue further research, with studies of higher methodological quality and longer follow-up, to refine both preventive and therapeutic strategies, and to ensure outcomes that are not only effective and durable, but also aesthetically satisfying for patients.

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## APPENDIX 1

Figure 1. Photographic adaptation of QLF.

Figure 2. Photographic adaptation of DIAGNODENT®.

Figure 4. Photographic adaptation of Electronic Caries Monitor ECM.

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Publication Title	Dental caries : the disease and its clinical management	Country	United Kingdom of Great Britain and Northern Ireland
Author / Editor	Fejerskov, Ole., Kidd, Edwina A. M.	Rightsholder	John Wiley & Sons - Books
Date	01/01/2008	Publication Type	Book
Language	English		
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Instructor Name	Mathilde Cretel	Expected Presentation Date	2025-07-19
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Volume / Edition	2nd ed.	Publication Date of Portion	2008-01-01
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## APPENDIX 2

Figure 5. Photographic adaptation of moderate fluorosis.

Figure 6. Photographic adaptation of traumatic hypomineralization.

Figure 7. Photographic adaptation of MIH.

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Article Title	Diagnosis and treatment options for anterior white spot lesions.	Start Page	348
Author / Editor	British Dental Association	End Page	352
Date	01/01/1997	Issue	6
Language	English	Volume	229
Country	United Kingdom of Great Britain and Northern Ireland	URL	<a href="http://www.nature.com/bdj/">http://www.nature.com/bdj/</a>
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Volume / Edition	229	Publication Date of Portion	2020-09-25
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## APPENDIX 3

Table 2. Classification of WSL.

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Article Title	White Spot Lesions During Orthodontic Treatment: Mechanisms and Fluoride Preventive Aspects	Start Page	183
Date	01/01/1995	End Page	193
Language	English	Issue	3
Country	United States of America	Volume	14
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Title	WHITE SPOT LESIONS IN ORTHODONTICS: COMPARISON OF THE IMPACT OF FIXED ORTHODONTICS APPLIANCES VERSUS ALIGNERS	Institution Name	Egas Moniz
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## APPENDIX 4

Figure 13. Photographic adaptation of intermaxillary elastics, hooks, and springs attached to metallic brackets.

Figure 14. Photographic adaptation of an aligner.

Figure 15. Photographic adaptation of an aligner with attachments.

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## APPENDIX 5





Figure 11. Photographic adaptation of lingual brackets.

Figure 18. MI Paste Plus (GC America Inc, Alsip, Illinois) is a water-based, sugar-free crème containing Recaldent casein phosphopeptide–amorphous calcium phosphate and fluoride.

Figure 19. White spot lesions before (A) and after (B) microabrasion.

Figure 20. Resin infiltration provides a minimally invasive treatment approach to transform the outer surface of affected teeth into a more permeable layer with the help of hydrochloric acid (HCl) etching, and infiltrating the porous structure beneath it using a TEGMA-based, low-viscosity resin.

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