Effectiveness of Bracket Sealants in Preventing White-Spot Lesions in Fixed Orthodontics - A Literature Review

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Abstract

AIM: To determine the extent to which sealants applied around orthodontic brackets reduce the risk of white-spot lesions (WSLs) as early signs of enamel demineralisation caused by inadequate oral hygiene.
METHODS: A search of the electronic database PubMed was performed and 35 English- or German-language articles published between 2015 and 2025 were included.
RESULTS: The use of bracket-area sealants can make a relevant contribution to the prevention of WSLs, particularly in high-risk patients. Effectiveness is material-dependent and influenced by correct application technique. In vivo data are heterogeneous, but in vitro studies consistently demonstrate the protective potential of sealants against enamel demineralisation adjacent to brackets.
CONCLUSION: Optimal oral hygiene combined with adjunctive fluoride measures remains the gold standard for WSL prevention. Sealants show promise and should be recommended as part of a comprehensive prevention strategy that includes personalised oral-hygiene instruction, dietary counselling and regular follow-up. Future developments in sealant materials and application methods offer further potential to enhance clinical effectiveness.

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1 Introduction

A key challenge in the orthodontic treatment of children and adolescents with fixed appliances lies in maintaining adequate oral hygiene. The fixed multibracket appliance increases the retention surface available for food debris and bacterial biofilm, thereby elevating the risk of caries (Attin, 2016). Early forms of enamel demineralisation manifest clinically as so-called white spot lesions (WSL) (Atack et al., 1996). As the aesthetic outcome of orthodontic treatment is often decisive for the patient, these lesions diminish the overall success of the treatment.

Orthodontic treatment with fixed appliances is a well-established procedure for correcting dental misalignments in children, adolescents, and adults. These corrections frequently require extensive tooth movement, which is feasible only with such appliances.

Despite advances in orthodontic materials and preventive strategies, the risk of caries development during orthodontic therapy with fixed appliances remains elevated (Lovrov et al., 2007). The brackets, bands, wires, residual adhesive material, worn bands, interlaced ligatures, power chains, springs, and numerous other anchoring or active components complicate mechanical cleaning and create increased plaque retention sites (Diedrich, 1981). In these regions, there is heightened colonisation by cariogenic microorganisms, notably *Streptococcus mutans* and lactobacilli. Through carbohydrate metabolism, these bacteria produce organic acids that lower the pH within the biofilm, initiating enamel demineralisation (Hellwig et al., 2013).

Particularly at risk are the smooth tooth surfaces adjacent to the brackets and the vulnerable zone between the bracket and the gingiva (Gorelick et al., 1982). Prolonged exposure to acidic conditions can result in the formation of white spot lesions.

Therefore, effective control of plaque accumulation, dietary management, and enamel protection via preventive measures such as fluoridation or the use of sealants represent significant challenges during orthodontic treatment with fixed appliances.

The clinical relevance of white spot lesions in orthodontics is considerable. Initial signs may appear after as little as four weeks of treatment (Khoroushi & Kachuie, 2017). Incidence rates as high as 97% have been reported in patients undergoing treatment with fixed appliances (Heymann & Grauer, 2013; Julien et al., 2013). Beyond aesthetic concerns, these lesions can progress into advanced carious defects.

Considering the rising number of orthodontic treatments during adolescence coupled with increasing aesthetic expectations, prevention, early diagnosis, and effective therapeutic interventions for WSL have become ever more important.

Several preventive approaches exist for mitigating WSL during fixed orthodontic therapy, including individual oral hygiene practices (Kossack & Jost-Brinkmann, 2005), fluoride applications in various formulations (Benson et al., 2019; Øgaard et al., 2001, 2006; Patano et al., 2023), smooth surface sealants (Kamber et al., 2021; Korkmaz & Yagci, 2019; Sardana et al., 2023; Tasios et al., 2019), nutritional education (Sardana et al., 2023), professional tooth cleaning (Jost-Brinkmann et al., 2000; Migliorati et al., 2015), and chemical reduction of microbial load (Gehlen et al., 2000; Kommuri et al., 2022). However, to date, there is no scientific consensus regarding the specific indications that warrant additional preventive interventions aimed at reducing WSL incidence during orthodontic therapy with fixed appliances.

The aim of the present study is to determine the extent to which coating agents, namely sealants can reduce the risk of white spot lesion development.

2 Methods

A systematic search of the PubMed electronic database was performed to address two principal questions: which methods are currently employed to prevent white spot lesions (WSLs), and to what extent sealant application prevents WSL development during orthodontic treatment with fixed appliances compared with other interventions. Searches were limited to studies published in English or German from 2015 onwards.

The following search terms were used singly and in combination: orthodontic; orthodontic treatment; white spot lesion; white spot lesions; decalcification; fluoride-containing bonding; fluoride adhesives; sealant. All combinations were run using capitalised Boolean operators (AND, OR, NOT). The principal search strings and the number of records retrieved were: (white spot lesion AND fluoride) — 280; (white spot lesion AND orthodontic) — 481; (white spot lesion AND fluoride-containing bonding) — 21; (white spot lesion AND fluoride adhesives) — 28; (white spot lesion OR decalcification AND sealant) — 38; (orthodontic AND white spot OR white lesion AND sealant) — 44.

Study eligibility was defined using a PICO framework: the population (P) comprised healthy patients of any age and ethnic background undergoing treatment with fixed multiband bracket appliances; the intervention (I) was sealant application for WSL prevention; the comparison (C) was a control group without sealant; and the outcome (O) comprised measures indicating reduced incidence, severity or progression of WSLs or reduced lesion size. Inclusion criteria therefore comprised studies of healthy participants of any age and ethnic origin treated with fixed multiband appliances. Both in vivo and in vitro studies were considered because the number of relevant clinical records was limited.

Exclusion criteria were studies focusing primarily on the treatment (rather than prevention) of WSLs, studies not involving orthodontic treatment with fixed appliances, studies of deciduous teeth, studies including patients with disabilities likely to affect oral hygiene performance, and studies using poorly described or clinically irrelevant protocols. Case reports, case series, editorials, letters, reviews without original data, animal studies and narrative reviews were excluded. Studies published in languages other than English or German or those that did not provide sufficient outcome data were also excluded.

Titles and abstracts of the identified records were screened against the predefined inclusion and exclusion criteria. Full texts of potentially relevant articles were then examined in detail; studies were excluded at this stage if they lacked sufficient data or did not correspond to the aims of the review. For all included studies the following information was extracted: authors, year of publication, study design, sample size for intervention and control groups, type of intervention and material or sealant used, characteristics of the control group, duration of observation, methods used to assess enamel demineralisation (for example microhardness testing, fluorescence analysis, microscopy or clinical indices), and outcome measures relating to WSL incidence, severity or progression.

After deduplication and application of all inclusion and exclusion criteria, 35 articles met the eligibility criteria and were included in the qualitative synthesis (**Figure 1**).

2.1 Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyze the textual content of the included studies. It is important to note that, given the narrative nature of this study, regression analysis and meta-analysis techniques were not deemed suitable for the analytical framework.

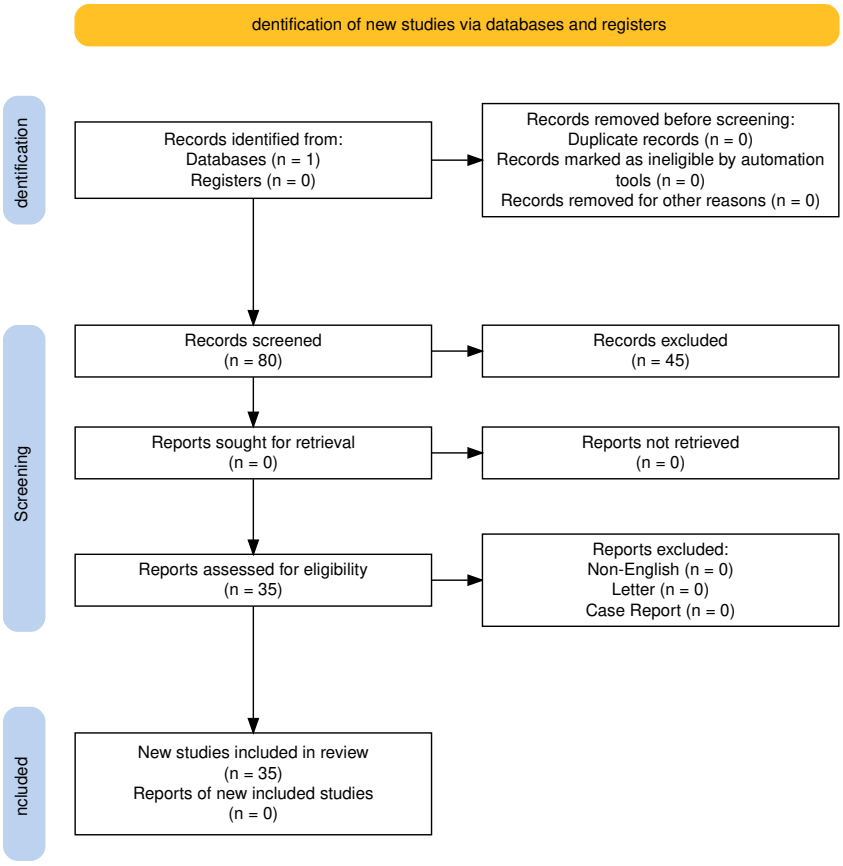

Figure 1. Article identification and selection process.

3 Results

3.1 Strategies for the prevention of white-spot lesions

The evidence on prevention strategies for WSL during orthodontic treatment is extensive. In this work, the specific search identified nine publications addressing the topic. As shown in **Table 1**, these comprised five reviews, two in vitro studies, one journal article and one consensus report.

Five authors reported that optimal oral hygiene, understood as regular and thorough tooth cleaning using specialised toothbrushes, specific interdental brushes and fluoride-containing toothpaste, forms the foundation for reduced plaque formation and thus risk reduction for WSL (Jost-Brinkmann et al., 2000; Migliorati et al., 2015). The recommendation is that toothpaste for daily use should contain more than 1,000 ppm fluoride, and 5,000 ppm fluoride for high-risk patients. A fluoride-containing toothpaste alone does not provide effective protection against WSL, even in patients with good oral hygiene (Khoroushi & Kachuie, 2017); therefore an individualised caries-management approach (including caries history, previous oral hygiene status, fluoride use, diet and systemic factors) should be established (Sardana et al., 2023).

The regular use of high-concentration fluoride gels, varnishes or rinses, or casein phosphopeptide–amorphous calcium phosphate (CPP-ACP) varnishes, represents an important adjunctive factor in the prevention of WSL (Bakdach & Hadad, 2020; Benson et al., 2019; Khoroushi & Kachuie, 2017; Nascimento et al., 2016; Patano et al., 2023; Pithon et al., 2015; Sardana et al., 2023; Tasios et al., 2019).

Table 1. Preventive strategies for white spot lesions.

AUTHOR (YEAR)	STUDY DESIGN	SAMPLE (N)	SAMPLE UNIT	INTERVENTIONS
Bakdach (2020)	Systematic review and meta-analysis	-	-	Topical fluoride
Benson (2019)	Review	1580	participants	Fluoride foam; Fluoride varnish; Fluoride toothpaste; Fluoride-releasing composite; Mouthrinses
Khoroushi (2017)	Journal article	-	-	Fluoride toothpaste
Nascimento (2016)	Systematic review and meta-analysis	1867	teeth	Fluoride varnish; Fluoride-releasing composite
Patano (2023)	Systematic review	-	-	Fluoride gels; Fluoride toothpaste; Fluoride varnish; Mouthrinses; Oral hygiene; Prophylaxis; Sealants
Pithon (2025)	In vitro study	120	teeth	CPP-ACP varnish
Sardana (2023)	Narrative synthesis / consensus statement	-	-	Diet; Fluoride applications; Fluoride toothpaste; Mouthrinses; Professional tooth cleaning; Re-evaluation; Reminders; Sealants; Individual caries management; Oral hygiene
Silva-Fialho (2021)	In vitro study	48	teeth	Fluoride toothpaste; Fluoride-releasing composite
Tasios (2019)	Systematic review	1427	participants	Fluoride varnish; Reminders; Sealants

Biological approaches, in the form of dietary modifications, were described in only one study (Sardana et al., 2023) but play an important and not-to-be-underestimated role.

In summary, a combination of various preventive strategies, particularly the application of topical fluorides in conjunction with optimised oral hygiene and patient-individualised measures, shows the most promising results in reducing the incidence of WSL. Several systematic reviews have confirmed the importance of structured prevention programmes.

3.2 Relevance of bonding agents and sealants

With regard to sealing the bracket area, a distinction should be made between bonding and adhesive systems and sealants, as both material groups potentially have a positive effect on the prevention of WSL around the bracket area.

Bonding agents. Considering the concept of minimal invasiveness, bonding and/or adhesive systems may serve as an adjunctive measure against the development of WSL around brackets. To assess their relevance, seven publications were identified in this work. As shown in **Table 2**, these comprise one review, three in vitro studies, one in vivo study and two clinical randomised trials (RCTs).

In the analysed in vitro studies, materials with additives such as selenium or fluoride produced a statistically significant inhibition of Streptococcus mutans growth compared with the control group (Krasniqi et al., 2020). Fluoride-containing adhesives also demonstrated an increased remineralisation potential. This could be further enhanced by the additional application of fluoride varnishes or CPP-ACP-containing varnishes (Senthilkumar et al., 2024). Moreover, lesion depths were significantly lower with the use of fluoride-containing materials than in the respective control groups (Velusamy et al., 2019).

In the included in vivo study no statistically significant difference in the prevention of white-spot lesions between the examined groups was observed (Oz et al., 2017).

Two randomised clinical trials reported, however, a reduction in the rate of demineralisation and a significantly lower Streptococcus mutans concentration in the biofilm with the use of resin-modified glass ionomer cements (RMGICs), and with fluoride-containing

Table 2. Effects of fluoride-containing versus non-fluoride adhesives and restorative materials.

AUTHOR (YEAR)	STUDY DESIGN	SPECIMENS/ PATIENTS	INTERVENTION	PRIMARY OUTCOME	RESULT
Alabdullah (2017)	RCT	600.0	G1: NFA; G2: AF	Demineralisation	diff N.S.
Andrucioli (2017)	RCT	29.0	G1: GIC; G2: C-resin	S. mutans	G1 < G2
Benson (2019)	REVIEW	1580.0	G1: GIC; G2: C-resin	WSL	N.S.
Krasniqi (2020)	IN VITRO	154.0	G1: AS; G2: AF; G3: control	S. mutans	G1 < G3; G2 < G3
Oz (2017)	IN VIVO	48.0	G1: AF; G2: NFA	WSL	diff N.S.
Senthilkumar (2024)	IN VITRO	60.0	G1: AF; G2: AF+fv; G3: AF+CPP-ACP; G4: NFA; G5: NFA+fv; G6: NFA+CPP-ACP	Remineralisation	G1 > G4
Velusamy (2019)	IN VITRO	24.0	G1: NFA; G2: AF; G3: AF+GIC	Lesion depth	G2 < G3

NOTE: AF = Adhesive with fluoride; NFA = Adhesive without fluoride; AS = Adhesive with Selenium; GIC = glass ionomer cement; C-resin = composite resin; fv = fluoride varnish; CPP-ACP = casein phosphopeptide–amorphous calcium phosphate; RMGIC = resin modified glass ionomer; S. mutans = Streptococcus mutans; WSL = White Spot Lesion; N.S. = not significant; G1–G6 = groups 1–6.

adhesives, respectively, compared with conventional composite adhesives (Alabdullah et al., 2017; Andrucioli et al., 2017).

In summary, the in vitro studies demonstrate a clear potential for fluoride- and selenium-containing materials to inhibit cariogenic bacteria and to promote remineralisation. Clinical study results are, however, inconsistent.

Sealants. Sixteen publications concerning sealants were identified. As shown in **Table 3**, these comprised four reviews, seven in vitro studies, one in vivo study, three randomised clinical trials and one consensus report. The studies followed diverse methodological approaches, resulting in heterogeneity of study designs, sample sizes and the sealant systems used.

Four systematic reviews were considered in the present analysis. Three of these reported a statistically significant reduction in WSL compared with the respective control groups (Kamber et al., 2021; Sardana et al., 2022; Tasios et al., 2019). Only one review found no statistically significant difference; however, that review included only a single study on sealants (Nascimento et al., 2016). Of particular note, Tasios et al. (2019) identified a relative risk of 0.8 (95% CI). Another review reported significantly lower initiation of WSL with the use of sealants and/or bonding systems, with $RR = 0.70$, as reported by Kamber et al. (2021).

Across the in vitro studies examined, a consistent significant reduction in WSL compared with untreated control groups was observed (Amaechi et al., 2021; Bergamo et al., 2023; Coordes et al., 2018; Paschos et al., 2016; Pithon et al., 2015; Premaraj et al., 2017; Wiewiora et al., 2018). In one study, microhardness testing and scanning electron microscopy demonstrated a highly significant difference between both sealants (ProSeal and Opal Seal) and the control group (Premaraj et al., 2017). Another study found that the control group exhibited significantly deeper lesions than all experimental groups (Amaechi et al., 2021).

Table 3. Summary of included studies assessing the effects of sealants and related preventive materials on enamel demineralisation and white spot lesions.

AUTHOR (YEAR)	STUDY DESIGN	SAMPLE (N)	SEALANT	METHODS	OUTCOME	RESULT
Amaechi (2021)	iviTro	53 teeth	Group 1: Control, Group 2: LLP, Group 3: DS-P, Group 4: DS-S, Group 5: RPS, Group 6: UOS, Group 7: DS-PS	TMR	LD	Gr. 1 > Gr. 2-7
Bergamo (2023)	iviTro	20 teeth	Group 1: DP, Group 2: CP Group 3: control	LCM	LD	Gr. 1, 2 < Gr. 3
Comert (2020)	iviVo	60 patients	Group 1: OS, Group 2: TB-P	LF	lesions	diff N.S.
Coordes (2018)	iviTro	120 teeth	Group 1: PS, Group 2: AG, Group 3: SP, Group 4: TF, Group 5: P, Group 6: FP	microscop	demin	Gr. 1 < Gr. 2-6
Flynn (2022)	RCT	40 patients	Group 1: CPP-ACP, Group 2: PS	SDP	EDI	diff N.S.
Hammad (2016)	RCT	50 patients	Group 1: SD-S, Group 2: Control	SDP	lesions	diff N.S.
Kamber (2021)	Review	1117 patients	34 different sealants or bonding materials	VTA / CLSM	WSL	sig. less
Korkmaz (2019)	RCT	48 patients	Group 1: APF, Group 2: fv, Group 3: PS, Group 4: Control	QLF	demin	Gr. 1,2,3 < Gr. 4
Nascimento (2016)	meta-a	1867 teeth	cementation materials, varnishes, sealants	-		diff N.S.
Paschos (2016)	iviTro	80 teeth	Group 1: CP, Group 2: PS, Group 3: AO, Group 4: FO	CLSM	LD	Gr 1,4 < Gr. 2,3
Pithon (2015)	iviTro	75 teeth	Group 1: b, Group 2: b+mr, Group 3: PS, Group 4: PS+b, Group 5: PS+b+mr	OCT	LD	Gr. 1 < Gr. 2, Gr. 1 < Gr. 3, Gr. 1 < Gr. 4, Gr. 1 < Gr. 5
Premaraj (2017)	iviTro	8 teeth	Group 1: PS, Group 2: OS, Group 3: Control	MH + SEM	p depth	Gr. 1 < Gr. 3, Gr. 2 < Gr. 3
Sardana (2022)	Review	29 trials	-	-	WSL	sealants prevent WSL
Sardana (2023)	cons rec	71 articles	-	-	WSL	sealants prevent WSL
Tasios (2019)	Review	1427 patients	Gr. 1 sealants, Gr. Control	-	WSL	Gr. 1 < Gr. 2
Wiewiora (2018)	iviTro	60 teeth	Group 1: VXT, Group 2: PS, Group 3: Control	FM + WL	LD	Gr. 1 < Gr. 2, Gr. 2 < Gr. 3

AG = Alpha-Glaze®, AO = AegisOrtho, b = brushing, CLSM = confocal laser scanning microscope, CP = Clinpro™ XT, DP = Duraphat, DS-P = DenteShield™ Primer, DS-PS = DenteShield™ Primer & Enamel Surface Sealant, DS-S = DenteShield™ Enamel Surface Sealant, EDI = enamel decalcification index, FM = fluorescence microscopy, FO = FujiOrthoLC, FP = Fluor Protector, fv = fluorid varnish, LD = lesion depth, LF = laser fluorescence measurements, LLP = Leopard Light Primer, MH = microhardness testing, mr = mouth rinse, OCT = Optical Coherence Tomography, OS = Opal Seal, P = Protecto®, PS = PRO SEAL®, QLF = Quantitative light-induced fluorescence images, RPS = Reliance Pro-Seal™, SD-S = SeLECT Defense™ sealant, SDP = standardized digital photographs, SEM = Scanning electron microscopy, SP = Seal&Protect®, TB-P = Transbond XT Primer, TF = Tiefenfluorid®, TMR = Transverse micro-radiography, UOS = Ultradent Opal-Seal™, VTA = visual-tactile assessment, VXT = Vanish XT, WL = white light

Thus, the application of sealants led to an effective reduction in lesion development. Other research groups corroborated the positive effect of sealants on enamel integrity by reporting significantly less severe lesions or stagnation of demineralisation in adjacent areas (Bergamo et al., 2023; Paschos et al., 2016).

Regarding clinical evidence, one in vivo study showed no significant difference between the groups (Comert & Oz, 2020). The randomised trials yielded partly heterogeneous results: one randomised controlled trial reported significantly less demineralisation in the sealant groups (Korkmaz & Yagci, 2019), whereas two studies found no significant differences (Flynn et al., 2022; Hammad & Knösel, 2016).

With respect to the efficacy of individual materials, ProSeal was found to be particularly effective in several studies. Coordes et al. (2018) demonstrated a significantly better protective effect against demineralisation compared with other fluoride-containing products (e.g. Alpha-Glaze, Seal&Protect, Tiefenfluorid, Protecto, Fluor Protector), with $p > 0.0001$. Furthermore, Premaraj et al. (2017) showed that ProSeal exhibited a shallower penetration depth than Opal Seal, indicative of a denser sealing.

In summary, the use of sealants can make a relevant contribution to the prevention of white spot lesions, particularly in high-risk patients. Efficacy is material-dependent and is influenced by correct application.

3.3 Future developments

The analysis of the eight studies presented in **Table 4** shows that bioactive adhesive systems in the current literature are increasingly investigated with respect to their antimicrobial and remineralising properties. In vitro studies predominate, complemented by a randomised controlled clinical trial and a systematic review.

In two studies a bioactive glass (BAG) was used exclusively as the adhesive component in in vitro experiments involving 90 teeth each. Both studies reported promotion of apatite formation as well as a pH-dependent effect on bond strength, indicating a remineralising

Table 4. Summary of included studies investigating bioactive adhesive materials and their reported effects on remineralisation and antibacterial activity.

AUTHOR (YEAR)	STUDY DESIGN	SAMPLE (N)	INTERVENTION	OUTCOME
Al-Eesa (2018)	iviTro	90.0	BAG–resin adhesive	Promoted apatite formation over time.
Al-Eesa (2019)	iviTro	90.0	BAG–resin adhesive	Promoted apatite formation during pH changes.
Al-Tuma (2021)	iviTro	12.0	n-CaF2 orthodontic primer	Higher cytotoxicity than control primer.
Al-Tuma (2023)	RCT (split-mouth)	31.0	n-CaF2 orthodontic primer	Reduced demineralisation scores; reduced S. mutans colonisation; no difference in WSL incidence.
Hamdi (2024)	Review	24.0	BAG; n-HAP; n-ACP; n-CaF2; AFCP; ABM	Greater remineralisation with additives versus control (p not reported).
Hussein (2024)	iviTro	50.0	GF + BAG primer	Improved antibacterial properties and remineralisation versus control (p not reported).
Lu (2023)	iviTro	8.0	Dual CMCS/ACP@PDA nanohybrid	Effective antibacterial and remineralising effect.
Nam Kim (2019)	iviTro	30.0	FGtBAG adhesive	Higher antibacterial and remineralisation effects versus control (p not reported).

Note. BAG = bioactive glass; GF = graphite fluoride; n-HAP = nano-hydroxyapatite; n-ACP = nano-amorphous calcium phosphate; n-CaF2 = nano-calcium fluoride; AFCP = fluorinated amorphous calcium phosphate nanoparticles; FGtBAG = graphite fluoride + BAG adhesive; WSL = white-spot lesion; ABM = ammonium-based methacrylate.

potential (Al-Eesa et al., 2018, 2019).

Another research group evaluated primers containing calcium fluoride nanoparticles. The results show higher cytotoxicity and a significantly reduced demineralisation compared with the control group (Al Tuma & Yassir, 2021, 2023).

In the randomised clinical trial a significantly lower bacterial colonisation was also found, without significant differences in the incidence of white spot lesions between the groups (Al Tuma & Yassir, 2023).

The systematic review analysed 24 articles and concluded that adhesives containing, among others, BAG, nano-hydroxyapatite, nano-amorphous calcium phosphate, nano-calcium fluoride, fluoridated amorphous calcium phosphate, or ammonium-based methacrylate monomer exhibit greater remineralising capacity than conventional materials (Hamdi et al., 2024). These results were confirmed in five of six in vitro studies (Al-Eesa et al., 2018, 2019; Hussein & Yassir, 2024; Lu et al., 2023; Nam et al., 2019).

Another study showed that a dual-bioactive nanohybrid of carboxymethyl chitosan (CMCS)-stabilised amorphous calcium phosphate (ACP) and polydopamine (PDA) likewise exhibited greater antibacterial efficacy and an enhanced remineralising effect compared with the control.

In summary, the use of bioactive components in adhesive systems is associated with a significant improvement in antimicrobial and remineralising properties in promising in vitro findings.

4 Discussion

This study investigated which methods for the prevention of WSL during orthodontic treatment with fixed appliances already exist and which innovations could be relevant independently of patient compliance.

Twenty-three of the 35 studies were published in the last six years (2019–2024), which suggests that this topic remains of high scientific interest.

The first major finding of this study is that a combination of different preventive strategies—particularly optimised oral hygiene combined with the application of topical fluorides and patient-individualised measures—shows the most promising results in reducing the incidence of WSL. Several systematic reviews have confirmed the importance of structured

prevention programmes.

All authors agreed that the regular use of high-concentration fluoride gels, varnishes or rinses, or CPP-ACP varnishes represents an important adjunct in the prevention of WSL (Bakdach & Hadad, 2020; Benson et al., 2019; Khoroushi & Kachuie, 2017; Nascimento et al., 2016; Patano et al., 2023; Pithon et al., 2015; Sardana et al., 2023; Tasios et al., 2019). These data can be regarded as robust, given the well established long-term and general pathogenesis of caries.

When examining patient-independent prevention strategies, some in vitro studies demonstrate clear potential of fluoride- and selenium-containing bonding materials to inhibit cariogenic bacteria and to promote remineralisation. Clinical study results, however, are inconsistent, and reliable statements about the superiority of individual bonding systems in vivo are not currently possible owing to limited evidence.

Another important finding of this work is that the use of sealants can make a relevant contribution to the prevention of WSL, particularly in high-risk patients.

The appraisal of sealer studies shows a heterogeneous picture. In the in vitro studies a consistent and significant reduction of WSL compared with untreated control groups was observed (Amaechi et al., 2021; Bergamo et al., 2023; Coordes et al., 2018; Paschos et al., 2016; Pithon et al., 2015; Premaraj et al., 2017; Wiewiora et al., 2018). By contrast, systematic reviews and randomised controlled clinical trials presented an inconsistent picture regarding efficacy. This discrepancy between laboratory and clinical findings can be explained by several methodological and practice-related aspects.

In vitro models are conducted under strictly controlled conditions in which confounding factors can be eliminated, such as individual hygiene measures, saliva composition and dietary habits. Under these standardised conditions a method can be investigated in isolation, without external influences that frequently occur in clinical reality. Clinical research, by contrast, is naturally confronted with a multitude of variable influences, for example differences in the individual oral microbiome, in home oral hygiene or in dietary behaviour; these can substantially affect the effectiveness of an intervention. Another central difference lies in the observation period. Whereas in vitro experiments are often designed over a few days or weeks, clinical studies frequently extend over the entire treatment period of a fixed appliances treatment. During this time additional processes (de- and remineralisation processes) and factors (abrasion of the sealer through chewing and brushing or bracket repairs) may play a role. Moreover, methodology varies between the two study designs. In vitro studies use highly sensitive and well validated methods such as transverse micro-radiography or fluorescence analyses to assess demineralisation. Clinical studies, by contrast, often rely on visual methods that have a higher susceptibility to subjective error. These differences hinder comparability.

This should not primarily be interpreted as a weakness of the sealer, but rather as an expression of the multiple influencing factors to which preventive measures are exposed in the oral environment. The protective effect demonstrated in vitro remains an important indication of preventive potential, even though additional measures such as optimal oral hygiene and regular check-ups are necessary in clinical practice to achieve the best possible effect.

Not least, systematic reviews and meta-analyses are limited in their comparability because of differences in study design, inclusion criteria and the various materials and analyses used.

Bonding systems can represent a supportive measure against the development of WSL at the bracket periphery; sealants can do so as well.

It is not yet conclusively determined whether a sealer for the prevention of WSL should be applied exclusively to selectively etched areas or to the entire labial tooth surface. For a successful seal a micro-retentive etch pattern is required, which, however, is associated with some loss of tissue. This loss of healthy dental hard tissue contradicts the primary aim of prevention and could be harmful in the long term. If, by contrast, only selective etching is performed and the sealer is applied to a limited area, the protective effect in critical regions, such as hard-to-reach areas between the gingival margin and the bracket, may be insufficient. Thus two concepts are opposed: on the one hand comprehensive protection of the entire surface at the cost of a small but existent substance loss; on the other hand a tissue-preserving approach that may result in incomplete prevention. The choice between these approaches should therefore always be made in the light of an individual risk assessment, balancing the benefit of broad protective coverage against the risks of additional enamel loss.

A further problem arises from the fact that in clinical practice frequently only the area that was selectively etched for bracket bonding is treated with a sealer. Parents and patients are often led to believe that the entire tooth is protected by the sealant. In fact, the preventive effect extends only to the limited etched area, while adjacent regions of the labial tooth surface that are likewise at increased caries risk remain unprotected. This discrepancy between the communicated protective effect and the actual sealed area raises not only clinical but also ethical questions regarding the duty to inform and the preventive self-concept of the treatment.

A further and final finding of this review concerned future materials. It can be stated, among other things, that the incorporation of bioactive components into adhesive systems is associated with a significant improvement in antimicrobial and remineralising properties in promising in vitro findings. Such innovations could not only increase the protective effect against WSL but also enable new approaches to overcome previous limitations. A promising prospect would be the development of sealers that either no longer require a micro-retentive etch pattern or are capable of fully remineralising the surface damage caused by etching without compromising protective efficacy. In addition, the use of fluorescent particles would be worth considering to visualise the sealing layer under special light sources, such as black light. This could substantially facilitate clinical monitoring of the durability and functionality of the sealer and provide early indication of whether refreshment or renewal of the seal is necessary.

Conclusions

Optimal oral hygiene combined with adjunctive fluoride measures continues to be the gold standard for the prevention of WSL. Despite heterogeneous in vivo data, in vitro results confirm the fundamental potential of sealants to protect against WSL.

Their use should therefore continue to be recommended, but embedded within a comprehensive prevention strategy that includes individual oral hygiene, dietary counselling and regular follow-up examinations. Future developments in the field of sealants also offer promising potential to further improve efficacy in the clinical setting.

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Not applicable.

Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Consent for publication

Not applicable.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

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