



Mini review

The impact of fixed orthodontic appliances on the development of white spot lesions: A mini review

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Abstract: *Background:* White spot lesions (WSLs) are the earliest clinical sign of enamel demineralisation and a frequent adverse outcome of fixed orthodontic therapy. Their development is multifactorial, reflecting an interaction between appliance, biofilm, and patient factors. *Objective:* This mini review summarises and critically evaluates the evidence published since 2018 on the contribution of fixed orthodontic appliances to the development of WSLs, with attention to pathogenesis, risk factors, and clinical implications. *Materials and methods:* A structured narrative review was conducted using PubMed/MEDLINE, Scopus, and Web of Science. Articles published between January 1, 2018 and September 30, 2025, were screened. Selected pre-2018 studies were retained for background on enamel demineralisation, biofilm behaviour, and orthodontic bonding. Search terms combined controlled vocabulary (MeSH) and free text keywords linked by Boolean operators, including “white spot lesions”, “enamel demineralization”, “fixed orthodontic appliances”, “orthodontic brackets”, “biofilm”, and “oral hygiene”. The initial search was not restricted by language, but only English-language full texts were retained during eligibility screening. *Results:* WSLs may develop at any stage of fixed orthodontic therapy, but the majority appear within the first three to six months after appliance placement. Lesions are observed most often on the labial and cervical enamel adjacent to brackets. Reported drivers include plaque retention around appliance components, an acidogenic and aciduric biofilm shift (dysbiosis), iatrogenic enamel changes from acid etching, and patient-level factors such as oral hygiene, diet, and treatment duration. *Discussion:* The change in the oral environment created by fixed appliances is necessary but not sufficient for WSL development. Patient-related factors, particularly oral hygiene and dietary behaviour, modulate the appliance-related risk. The first three to

six months after bonding is the period of greatest enamel vulnerability and the optimal window for individualised preventive intensification. *Conclusions:* WSLs are common but largely preventable. Risk-based, individualised preventive programmes initiated at the start of treatment, combined with sound bonding technique and careful biofilm control, are essential for protecting enamel and safeguarding the aesthetic outcome of fixed orthodontic therapy.

Keywords: impact; fixed orthodontic appliances; white spot lesions; enamel demineralisation; orthodontics; dental biofilm; dysbiosis

1. Introduction

White spot lesions (WSLs) represent the earliest clinically detectable demineralisation of tooth enamel and correspond to the pre-cavitated, non-cavitated stage of the carious process. Clinically, WSLs appear as chalky, opaque white areas because subsurface mineral loss increases enamel microporosity and alters its optical properties [1]. Although the surface layer often remains macroscopically intact, the subsurface structure is compromised, with consequences for both dental health and aesthetics. If demineralisation is not arrested, the lesion may progress to cavitation; even when arrested, the visual change can persist for years, affecting the aesthetic outcome of orthodontic treatment [1,2].

WSLs arise when the dynamic balance between enamel demineralisation and remineralisation is disrupted. Acidogenic bacteria such as *Streptococcus mutans* and *Lactobacillus* spp. metabolise fermentable carbohydrates within the dental biofilm and lower the local pH below the critical threshold for hydroxyapatite stability, leading to subsurface mineral loss [2,3]. Repeated acid challenges overcome the buffering capacity of saliva and the protective effect of fluoride, sustaining a demineralising environment.

Susceptibility to WSLs is multifactorial. Patient-related determinants with the strongest evidence base include poor oral hygiene with mature plaque biofilm, frequent intake of fermentable carbohydrates, reduced salivary flow and buffering capacity, and limited fluoride exposure in younger patients with immature enamel [3,4]. These factors typically act in combination rather than in isolation. In recent years, an oral microbiome shift towards an acidogenic and aciduric community described as a state of dysbiosis has emerged as an important mechanism linking biofilm maturation to enamel demineralisation in orthodontic patients [5].

Fixed orthodontic appliances are widely used to correct malocclusion and to achieve occlusal and facial balance, but their components (brackets, archwires, ligatures, and bonding materials) create retentive surfaces that promote biofilm accumulation [6]. Mechanical biofilm control is more difficult around these structures, and chronic plaque accumulation is frequently observed at the cervical and gingival margins of bracket bases, although the magnitude of this effect varies with patient compliance, oral hygiene practices, and preventive interventions [6,7].

Among appliance-related factors, the plaque retentive geometry and the iatrogenic enamel changes induced by acid etching during bonding appear to carry the greatest weight in the published literature [8]. Acid etching increases enamel surface area, roughness, and porosity, and adhesive remnants at the bracket periphery further support biofilm retention. After appliance debonding, the enamel of established WSLs does not remineralise completely, leaving a visible deficit that compromises aesthetic outcomes and patient satisfaction [9,10].

WSLs are, therefore, a common and clinically meaningful adverse event of fixed orthodontic therapy. Their management often requires additional preventive or microinvasive interventions, and their persistence can undermine the perceived success of treatment [11]. The relative weight of appliance-related, biofilm-related and patient-related factors, however, remains incompletely characterised. The aim of this mini review is to summarise and critically appraise the evidence published since 2018 on the association between fixed orthodontic appliances and the development of WSLs, with a focus on contributing factors, pathogenesis, and clinical implications.

2. Materials and methods

2.1. Study design and rationale

This work was designed as a structured narrative review. A narrative approach was selected because of the heterogeneity of the available clinical evidence, observational, *in vitro*, and *in situ* situations which does not allow meaningful quantitative pooling. The review followed published recommendations for narrative reviews in biomedical research, with an *a priori* protocol covering objective, search strategy, eligibility criteria, and synthesis approach.

2.2. Review question

The review question was as follows: In patients undergoing fixed orthodontic therapy, how do appliance-related, biofilm-related, and patient-related factors contribute to the development of WSLs? The exposure of interest was treatment with fixed orthodontic appliances; the outcome of interest was the occurrence, distribution, and severity of WSLs and the underlying enamel demineralisation. The review question, the manuscript title, and the search strategy were aligned to this single focus.

2.3. Literature search strategy

PubMed/MEDLINE, Scopus, and Web of Science were searched for articles published between January 1, 2018 and September 30, 2025. Selected pre-2018 studies were retained when they provided foundational information on enamel demineralisation, oral biofilm behaviour, or orthodontic bonding.

Search terms combined Medical Subject Headings (MeSH) and free text keywords using Boolean operators. The core search string was: (“white spot lesion” OR “enamel demineralisation” OR “enamel demineralization”) AND (“fixed orthodontic appliance” OR “orthodontic bracket” OR “archwire” OR “orthodontic bonding”) AND (“biofilm” OR “plaque” OR “oral hygiene” OR “oral microbiome”).

Database-specific filters and synonym variants were applied as required. Reference lists of included studies were screened manually for additional eligible articles. No language filter was applied at the database stage; only English-language full texts were retained at the eligibility step, and this constraint is acknowledged as a potential source of selection bias.

2.4. Eligibility criteria

Inclusion criteria were (i) peer reviewed studies on human enamel evaluating the occurrence, extent, or severity of WSLs or enamel demineralisation; (ii) clinical, observational, *in vitro*, or *in situ*

studies addressing fixed orthodontic appliances or their components (brackets, archwires, ligatures, bonding materials); (iii) studies addressing aetiology, risk factors, biofilm features, enamel changes, or clinical implications of WSLs; and (iv) review articles providing mechanistic or contextual background. Exclusion criteria were: (i) studies without sufficient methodological detail; (ii) studies limited to removable appliances or aligners with no fixed appliance comparator; (iii) case reports, short communications, editorials, and conference abstracts; and (iv) randomised controlled trials of preventive or therapeutic interventions in non-fixed orthodontic settings.

2.5. Study selection

Records identified through the database searches and manual reference screening were de-duplicated and then assessed by title and abstract for relevance to the review question. Potentially eligible articles underwent full-text review against the inclusion and exclusion criteria. Selected studies were then included in the narrative synthesis.

2.6. Data extraction and synthesis

Data were extracted descriptively, focusing on enamel demineralisation, biofilm behaviour, appliance characteristics, and patient-level factors. Findings were grouped into prespecified themes (timing of lesion development, anatomical distribution, contributing factors, diagnosis, and detection) and synthesised qualitatively. Because the included studies were heterogeneous in design and outcome definition, no quantitative pooling was attempted.

2.7. Methodological quality and limitations

A formal risk of bias assessment was not performed. The decision is consistent with the narrative design of the review and the marked heterogeneity of study methodologies, but it is acknowledged as a limitation: differences in methodological quality between clinical and observational studies may influence the strength and consistency of the conclusions drawn.

3. Results

3.1. Timing of WSL development

Across the included clinical and observational studies, WSLs most frequently appeared during the early phase of fixed orthodontic treatment, with the majority of lesions developing within the first three to six months after appliance bonding [12]. This early vulnerability coincides with the establishment of new plaque retentive surfaces, the patient's adaptation to oral hygiene routines around the appliance, and the iatrogenic enamel changes induced by bonding [13]. Variability between cohorts was substantial and reflected differences in oral hygiene support, preventive regimens, and study design.

3.2. Anatomical distribution

WSLs predominantly affected the labial and cervical enamel adjacent to bracket bases, where

biofilm accumulation is greatest [12]. Anterior teeth were more often involved in studies that reported lesion distribution. Some studies reported a more uniform distribution when patients with consistently poor oral hygiene were analysed separately, indicating that anatomical patterns are modulated by behavioural factors.

3.3. Contributing factors

Three groups of factors contributed to WSL development:

- **Appliance-related factors:** Bracket geometry and surface characteristics, ligature type, archwire size, and the presence of adhesive remnants all increase plaque retentive area. The available evidence does not support a consistent effect of bracket material per se (metal versus ceramic) on the extent of enamel decalcification; the dominant appliance-related drivers are surface roughness around the bracket and the bonding procedure itself [13,14].
- **Biofilm-related factors:** Microbiological studies report a shift in the subgingival and supragingival biofilm towards a more acidogenic and aciduric community after appliance placement, consistent with a dysbiotic state. This shift correlates with poor oral hygiene and is implicated in the maintenance of the low pH environment required for subsurface demineralisation [5,15].
- **Patient-related factors:** Poor oral hygiene, high plaque indices, frequent intake of fermentable carbohydrates, and prolonged treatment duration consistently emerge as the strongest correlates of WSL occurrence and severity, often outweighing appliance-related differences within the same cohort [16,17].

Several in vitro and in situ studies reported reductions in enamel microhardness and increases in surface roughness around bracket bases after simulated cariogenic challenges [18]. These findings should be interpreted as mechanistic support for the clinical observations rather than direct confirmation of in vivo lesion development; the translational limitations of laboratory models are addressed in Section 4.

3.4. Diagnosis and detection of WSLs

Most orthodontists continue to rely on visual inspection, supplemented by clinical photographs, for WSL diagnosis. Adjunctive quantitative aids in light-induced fluorescence (QLF), DIAGNOdent, and digital imaging improvement in early detection and allow objective monitoring of lesion progression [19].

Within the International Caries Detection and Assessment System (ICDAS), code 1 lesions are visible only after sustained air drying of the enamel surface, whereas code 2 lesions can also be detected on wet enamel. This distinction is operationally important during orthodontic treatment, because routine visual screening without air drying will underdetect code 1 lesions and may delay the introduction of preventive measures [19,20].

4. Discussion

This review confirms that WSL development during fixed orthodontic therapy is multifactorial, but the synthesised evidence allows the relative contribution of the major drivers to be appraised more explicitly than in earlier overviews. Patient-related factors, particularly oral hygiene behaviour, dietary frequency, and treatment duration, emerged as the strongest and most consistent correlates of WSL occurrence and severity within cohorts that received similar appliances, while appliance-related factors

set the upper limit of biofilm retentive opportunity but rarely overrode patient behaviour [16,17]. This pattern supports a risk-based rather than appliance-centric framing of prevention.

Among biofilm-related mechanisms, the shift towards an acidogenic and aciduric community after bonding (dysbiosis) is one of the better supported pathways linking appliance placement to enamel demineralisation [5,15]. The contribution of iatrogenic enamel changes from acid etching is biologically plausible and supported by laboratory data, but the magnitude of its independent clinical effect remains uncertain [13]. Conflicting findings on bracket material suggest that surface characteristics and bonding technique matter more than the choice between metal and ceramic, although heterogeneity in study design limits firm conclusions [14,18].

The first three to six months after appliance placement is consistently identified as the period of greatest enamel vulnerability and is the logical window for intensifying preventive measures. Risk assessment at the start of treatment, individualised oral hygiene instruction, high fluoride regimens, and, where indicated, professional applications such as fluoride varnish or resin sealants are supported by the available evidence as components of an early preventive package [21,22]. Reactive treatment of established lesions alone is not sufficient.

From a clinical perspective, WSLs that fail to remineralise after debonding can compromise the aesthetic success of orthodontic treatment and contribute to patient dissatisfaction. Enamel preservation should therefore be considered an outcome of orthodontic care alongside tooth alignment and occlusal correction [23,24].

4.1. Gaps in current evidence

Several specific gaps remain in the current literature. First, few studies disentangle the independent contribution of acid etching–induced enamel changes from biofilm-driven demineralisation *in vivo*. Second, the long-term reversibility of WSLs after debonding is poorly characterised, with most studies reporting follow-up of less than 12 months [10]. Third, comparative data on novel preventive bioactive technologies bonding materials, antimicrobial bracket coatings, or self-assembling peptides are limited to short-term laboratory or small cohort studies [25]. Fourth, patient compliance, which strongly modulates risk, is reported inconsistently and rarely measured objectively.

4.2. Limitations

This review has several limitations. As a structured narrative review, it did not include a formal risk of bias assessment or quantitative synthesis, and the findings are therefore vulnerable to the same selection and reporting biases as other narrative reviews. Restriction of full-text screening to English-language articles may have excluded relevant work published in other languages. The included studies differed in design, population, case definition, and outcome measures, limiting direct comparison. Finally, much of the evidence on enamel behaviour and biofilm dynamics is derived from short-term *in vitro* and *in situ* models, which approximate but do not fully replicate the long duration and biological complexity of clinical orthodontic treatment.

4.3. Future directions

Priorities for future research include long-term, prospective clinical trials with standardised,

quantitative WSL assessment to characterise lesion progression, regression, and aesthetic stability after debonding. Comparative trials of bioactive orthodontic materials, antimicrobial surface treatments, and risk-stratified preventive programmes are needed to translate mechanistic findings into clinically meaningful protection of enamel. Improved characterisation of the orthodontic appliance/oral microbiome interaction, including objective measurement of patient compliance, would strengthen the evidence base supporting individualised preventive care [25].

5. Conclusions

WSLs during fixed orthodontic therapy arise from the interaction of appliance design, biofilm dysbiosis, patient compliance, and dietary behaviour. Enamel is most vulnerable during the first three to six months after appliance placement, which is the optimal window for intensified preventive care. WSL development is common but largely preventable when aetiology and individual risk are recognised and managed early. Enamel preservation should be regarded as a core orthodontic outcome.

Authors' contributions

A.K. and E.N. conceptualized the scope and framework of the narrative mini-review. A.K., S.G., and E.N. performed the literature search, article screening, and data extraction. A.K. and S.G. drafted the original manuscript, while E.M. and A.A. critically revised the manuscript for important intellectual and scientific content. All authors participated in the final editing, read, and approved the submitted version of the manuscript.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflict of interest.

References

1. Z. Xie, L. Yu, S. Li, J. Li, Y. Liu, Comparison of therapies of white spot lesions: A systematic review and network meta-analysis, *BMC Oral Health*, **23** (2023), 346. <https://doi.org/10.1186/s12903-023-03076-x>
2. F. M. Levy, A. S. Braga, V. T. Pelá, S. Lavender, D. Zhang, S. Pilch, et al., Characterization of white spot lesions formed on human enamel under microcosm biofilm for different experimental periods, *J. Appl. Oral Sci.*, **30** (2022), e20210560. <https://doi.org/10.1590/1678-7757-2021-0560>
3. M. Ando, S. Shaikh, G. Eckert, Determination of caries lesion activity: Reflection and roughness for characterization of caries progression, *Oper. Dent.*, **43** (2018), 301–306. <https://doi.org/10.2341/16-236-L>

4. S. Martignon, A. G. Roncalli, E. Alvarez, V. Aránguiz, C. A. Feldens, M. A. R. Buzalaf, Risk factors for dental caries in Latin American and Caribbean countries, *Braz. Oral Res.*, **35** (2021), e053. <https://doi.org/10.1590/1807-3107bor-2021.vol35.0053>
5. A. Lucchese, L. Bondemark, M. Marcolina, M. Manuelli, Changes in oral microbiota due to orthodontic appliances: A systematic review, *J. Oral Microbiol.*, **10** (2018), 1476645. <https://doi.org/10.1080/20002297.2018.1476645>
6. J. S. An, B. S. Lim, S. J. Ahn, Managing oral biofilms to avoid enamel demineralization during fixed orthodontic treatment, *Korean J. Orthod.*, **53** (2023), 345–357. <https://doi.org/10.4041/kjod23.184>
7. C. Erbe, C. Jacobs, M. Klukowska, H. Timm, J. Grender, H. Wehrbein, A randomized clinical trial to evaluate the plaque removal efficacy of an oscillating-rotating toothbrush versus a sonic toothbrush in orthodontic patients using digital imaging analysis of the anterior dentition, *Angle Orthod.*, **89** (2019), 385–390. <https://doi.org/10.2319/080317-520.1>
8. I. Vouros, G. N. Antonoglou, S. Anoixiadou, S. Kalfas, A novel biofilm removal approach (Guided Biofilm Therapy) utilizing erythritol air-polishing and ultrasonic piezo instrumentation: A randomized controlled trial, *Int. J. Dent. Hyg.*, **20** (2022), 381–390. <https://doi.org/10.1111/idh.12533>
9. J. D. O. Farias, M. C. A. Cunha, V. L. Martins, P. Mathias, Microinvasive esthetic approach for deep enamel white spot lesion, *Dent. Res. J.*, **19** (2022), 29. <https://doi.org/10.4103/1735-3327.340114>
10. S. M. Fathy, A. Abdelhafez, F. A. Darwesh, T. A. Elkhooly, Evaluation of incipient enamel-carious-like lesion treated with hydroxyapatite-chitosan nanocomposite hydrogel, *J. World Fed. Orthod.*, **13** (2024), 211–220. <https://doi.org/10.1016/j.ejwf.2024.04.001>
11. X. Ma, X. Lin, T. Zhong, F. Xie, Evaluation of the efficacy of casein phosphopeptide-amorphous calcium phosphate on remineralization of white spot lesions in vitro and clinical research: A systematic review and meta-analysis, *BMC Oral Health*, **19** (2019), 295. <https://doi.org/10.1186/s12903-019-0977-0>
12. K. C. Julien, P. H. Buschang, P. M. Campbell, Prevalence of white spot lesion formation during orthodontic treatment, *Angle Orthod.*, **83** (2013), 641–647. <https://doi.org/10.2319/071712-584.1>
13. B. L. Blochberger, J. Symmank, Á. Nitzsche, S. Nietzsche, F. Steiniger, A. Guellmar, Influence of the orthodontic bonding procedure on biofilm formation, *Orthod. Craniofacial Res.*, **27** (2024), 95–101. <https://doi.org/10.1111/ocr.12692>
14. N. A. Almosa, B. S. Sibai, O. A. Rejjal, N. Alqahtani, Enamel demineralization around metal and ceramic brackets: An *in vitro* study, *Clin. Cosmet. Invest. Dent.*, **11** (2019), 37–43. <https://doi.org/10.2147/CCIDE.S190893>
15. Q. Wang, J. Ma, B. Wang, X. Zhang, Y. Yin, H. Bai, Alterations of the oral microbiome in patients treated with the Invisalign system or with fixed appliances, *Am. J. Orthod. Dentofacial Orthop.*, **156** (2019), 633–640. <https://doi.org/10.1016/j.ajodo.2018.11.017>
16. Ç. Toti, A. Meto, G. Kaçani, E. Droboniku, D. Hysi, M. Tepedino, et al., White spots prevalence and tooth brush habits during orthodontic treatment, *Healthcare*, **10** (2022), 320. <https://doi.org/10.3390/healthcare10020320>
17. L. J. Walsh, D. L. Healey, Prevention and caries risk management in teenage and orthodontic patients, *Aust. Dent. J.*, **64** (2019), S37–S45. <https://doi.org/10.1111/adj.12671>

18. I. Tušek, B. O'rourke, C. Lekić, J. Tušek, B. Tušek, Early childhood caries in multilingual community, *Cent. Eur. J. Public Health*, **28** (2020), 286–291. <https://doi.org/10.21101/cejph.a6345>
19. D. Sardana, S. Manchanda, M. Ekambaram, Y. Yang, C. P. McGrath, C. K. Y. Yiu, Prevention of demineralization during multi-bracketed fixed orthodontic treatment: An overview of systematic reviews, *Int. J. Paediatr. Dent.*, **32** (2022), 473–502. <https://doi.org/10.1111/ipd.12927>
20. A. Meto, B. Colombari, A. Odorici, L. B. Giva, E. Pericolini, A. L. Regina, Antibacterial effects of MicroRepair®BIOMA-Based toothpaste and chewing gum on orthodontic elastics contaminated in vitro with saliva from healthy donors: A pilot study, *Appl. Sci.*, **10** (2020), 6721. <https://doi.org/10.3390/app10196721>
21. D. Sardana, M. Ekambaram, Y. Yang, C. P. McGrath, C. K. Y. Yiu, Caries-preventive effectiveness of two different fluoride varnishes: A randomised clinical trial in patients with multi-bracketed fixed orthodontic appliances, *Int. J. Paediatr. Dent.*, **33** (2023), 50–62. <https://doi.org/10.1111/ipd.13013>
22. M. Sonesson, S. Twetman, Prevention of white spot lesions with fluoride varnish during orthodontic treatment with fixed appliances: A systematic review, *Eur. J. Orthod.*, **45** (2023), 485–490. <https://doi.org/10.1093/ejo/cjad013>
23. P. Rechmann, S. Bekmezan, B. M. T. Rechmann, B. W. Chaffee, J. D. B. Featherstone, MI Varnish and MI Paste Plus in a caries prevention and remineralization study: A randomized controlled trial, *Clin. Oral Invest.*, **22** (2018), 2229–2239. <https://doi.org/10.1007/s00784-017-2314-9>
24. E. B. Oregani, A. Jafari, S. M. Sajedi, S. R. Motamedian, Preventive effect of professional fluoride supplements on enamel demineralization in patients undergoing fixed orthodontic treatment: A systematic review and meta-analysis, *Turk. J. Orthod.*, **35** (2022), 223–230. <https://doi.org/10.5152/TurkJOrthod.2022.21050>
25. L. N. Flynn, K. Julien, A. Noureldin, P. H. Buschang, The efficacy of fluoride varnish vs a filled resin sealant for preventing white spot lesions during orthodontic treatment, *Angle Orthod.*, **92** (2022), 204–212. <https://doi.org/10.2319/052521-418.1>



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