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Review Article

Enamel Surface Alterations After Orthodontic Debonding: A Comprehensive Review of Bracket Materials, Future Perspectives and Comparisons

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Abstract

Orthodontic treatment, while highly effective in correcting malocclusions, continues to pose challenges in minimizing iatrogenic enamel damage during the debonding of appliances. This systematic review explores the spectrum of enamel alterations following orthodontic debonding, evaluates the differential effects of various bracket materials, and outlines future directions for enamel preservation. The discussion encompasses physical modifications such as increased surface roughness, crack formation, and volumetric enamel loss, as well as chemical alterations including demineralization and the appearance of white spot lesions. Quantitative findings report enamel loss ranging from $0.02 \pm 0.01 \text{mm}^3$ *to* $0.61 \pm 0.51 \text{mm}^3$ *per tooth. Comparative evidence reveals that ceramic brackets, although aesthetically favourable, are more frequently associated with enamel damage, heightened surface roughness, and demineralization owing to their strong adhesion and brittleness, which increases fracture risk upon debonding. Metal brackets, in contrast, tend to exert a lower risk of direct enamel deterioration. Other systems, such as self-ligating, lingual appliances, and clear aligners, also impact enamel, necessitating specific debonding and clean-up approaches. The review critically examines debonding techniques and adhesive removal strategies, with tungsten carbide burs noted for producing reduced roughness compared to alternatives. Looking forward, promising avenues include adhesive formulations with remineralizing capabilities, novel bracket designs that enable atraumatic debonding, and refined enamel conditioning protocols. Ultimately, the overarching goal is to achieve orthodontic correction while prioritizing enamel integrity, thereby ensuring both functional and aesthetic outcomes through continued research and adaptive clinical practice.*

Keywords: *Orthodontic debonding, Enamel surface alterations, Bracket materials, Enamel damage, Surface roughness, Demineralization, White spot lesions, Adhesive removal, Enamel preservation, Future perspectives.*

1. Introduction

Orthodontic treatment plays a crucial role in modern dentistry, not only correcting malocclusions but also enhancing function and aesthetics. However, one constant concern is the potential for iatrogenic enamel damage during both bonding and, more importantly, debonding procedures[1]. The primary clinical objective is to return enamel to a condition as close as possible to its original state following the removal of brackets and adhesive materials[2,3].

This review explores the nature of enamel alterations following orthodontic debonding, the influence of different bracket materials, and current strategies to limit such damage. Quantitative estimates of enamel loss, crack formation, and surface roughness are presented, with comparisons between ceramic and metal brackets [4]. Finally, potential measures to reduce enamel alterations during debonding and clean-up are discussed [5].

2. Surface Characteristics of Enamel Before Debonding

Understanding enamel's baseline properties its microscopic features, chemical composition, and surface roughness is essential before orthodontic treatment begins [4]. Establishing this baseline provides a reference point for identifying iatrogenic changes caused by treatment and helps guide the development of protective strategies[1].

The ideal debonding procedure should be quick, comfortable, and preserve enamel integrity[6] Yet, in practice, some degree of enamel alteration almost always occurs. Minimizing this requires careful technique and the use of appropriate materials [4,7]. Recent advances, such as three-dimensional optical scanners, have made it possible to measure even minor enamel surface changes with high precision[8]. The ultimate goal is to remove brackets and bonding agents a traumatically, restoring the enamel to its pre-treatment state while maintaining safety for patients and dental professionals [9].

3. Enamel Surface Alterations After Orthodontic Debonding

Fixed orthodontic appliances inevitably leave their mark on enamel surfaces, causing physical, chemical, and aesthetic alterations.

3.1 Physical Alterations: Roughness, Cracks, and Hard Tissue Loss

3.1.1 Surface Roughness

Enamel roughness is commonly observed after bracket removal and adhesive clean-up, particularly when ceramic brackets are used [4,10]. Once roughness or deep scratches develop, they are unlikely to smooth out naturally through routine brushing[1]. Ceramic brackets tend to increase enamel roughness more than metal brackets[4]. Enamel loss associated with adhesive removal has been quantified between 0.02 ± 0.01 mm³ and 0.61 ± 0.51 mm³ per tooth [5]. These findings highlight the importance of strategies designed to minimize loss of enamel during orthodontic treatment.

3.1.2 Cracks and Substance Loss

Studies differ on whether debonding itself introduces new cracks, though ceramic brackets due to their brittleness are often associated with this risk [4,11]. Existing cracks or surface fissures may worsen, accompanied by adhesive remnants or partial loss of enamel prism structure[4]. Volumetric enamel loss following debonding and adhesive removal has been documented in the same range[5], with some cases showing 20–50 µm of hard tissue loss during clean-up after metal bracket debonding [4,8]. Such damage may lead to sensitivity, greater susceptibility to caries, and even pulpal inflammation[3]. Hence, both bracket choice and debonding protocols significantly influence the long-term preservation of enamel [12,5].

3.2 Chemical Alterations: Demineralization and White Spot Lesions

3.2.1 Demineralization

One of the most frequent complications of fixed appliances is enamel demineralization, often manifesting as white spot lesions (WSLs) [13,15]. These lesions typically form around brackets, bands, and ligatures in plaque-retentive zones [14]. Contributing factors include inadequate oral hygiene and the acid etching required for bonding, which can penetrate 5–25 µm into the enamel [14,15].

3.2.2 White Spot Lesions (WSLs)

WSLs may develop within a month of bracket placement and can extend up to 100 µm into the enamel[16]. Orthodontic patients exhibit a significantly higher prevalence of WSLs compared to non-orthodontic populations [15]. Left untreated, these lesions can progress to cavitation while also presenting aesthetic challenges [15]. Their prevention and management are therefore critical throughout treatment [13].

3.3 Aesthetic Alterations: Enamel Colour

In addition to physical and chemical changes, orthodontic treatment can affect enamel colour. Colour alterations may result from demineralization, residual adhesive, or reshaping of enamel during polishing [17]. Although enamel loss has been extensively documented, enamel colour change has only recently become an area of focused research [17].

4. Comparative Review of Bracket Materials

The material used for orthodontic brackets significantly impacts the type and extent of enamel alterations after debonding.

4.1 Metal Brackets

Metal brackets, typically made from alloys, are widely used due to their durability and cost-effectiveness [4]. Following debonding, residual adhesive removal often leads to enamel loss in the range of 20–50 µm [4,8]. Importantly, the lower bond strength of metal brackets compared to ceramics reduces the likelihood of enamel damage during removal (4). However, both bracket types are associated with increased enamel roughness [4].

4.2 Ceramic Brackets

Ceramic brackets, such as those made from Al_2O_3 or zirconia, are valued for their aesthetic appeal but carry a higher risk of enamel damage [4]. They have been shown to increase enamel roughness and demineralization, especially in central tooth regions, more than metal brackets. Their high bond strength and brittle nature often result in bracket fracture during debonding occurring in over 60% of cases and leave behind fragments requiring further removal [4]. Cleaning fractured remnants typically involves high-speed grinding, which, if not carefully controlled, may risk pulpal injury. Hence, ceramic brackets require meticulous handling to minimize iatrogenic enamel damage [4].

4.3 Self-Ligating Brackets

Self-ligating brackets, available in both metal and ceramic forms, are designed to reduce friction and may shorten treatment time. However, evidence directly linking them to enamel changes is limited. Some studies suggest they increase microbial plaque retention, raising the risk of demineralization [19]. More research is needed to understand their long-term effects on enamel surface integrity.

4.4 Lingual Brackets and Clear Aligners

Although less frequently studied, lingual brackets have also been linked to enamel roughness after debonding, even following polishing [20]. Clear aligners, while generally associated with better periodontal health compared to fixed appliances [21], still require bonded attachments. The removal of these attachments can also result in volumetric enamel loss during clean-up [5]. While aligners may be linked with less root resorption than fixed appliances[22], more focused investigations are needed to evaluate their full impact on enamel surfaces.

5. Debonding and Clean-Up Techniques: Minimizing Enamel Damage

The choice of debonding technique and adhesive removal method is critical to enamel preservation.

5.1 Debonding Methods

Pliers applying compressive, shear, or tensile forces are commonly used [23]. The base-debonding method tends to generate less stress on enamel compared to wing-based approaches[24]. Ideally, adhesive should remain on the enamel surface rather than being removed along with enamel fragments [4].

5.2 Adhesive Removal and Polishing

After debonding, residual adhesive must be removed for both aesthetic and oral health reasons [25]. Techniques include low- or high-speed burs (tungsten carbide, diamond, zirconia, or white stone), manual scrapers, ultrasonic instruments, sandblasting, or lasers[26,27]. Systematic reviews suggest tungsten carbide burs create the least surface roughness (6). Magnification tools can improve precision and reduce enamel damage during this stage[25].

5.3 Enamel Protection Considerations

Complete adhesive removal is vital, but overly aggressive polishing risks unnecessary enamel loss. Conversely, leaving behind adhesive residues promotes plaque accumulation and demineralization [5,26]. The clinical challenge lies in striking the right balance between thorough cleaning and enamel preservation.

6. Future Perspectives and Innovations in Enamel Preservation

Advancements in orthodontic materials and methods increasingly focus on protecting enamel throughout treatment.

6.1 Novel Adhesive Systems

Current research aims to create adhesives that provide sufficient strength during treatment but allow easier removal with minimal residue [28]. Self-etching systems, calcium phosphate-based conditioners, and primers incorporating nanoparticles such as hydroxyapatite (nHA) or amorphous calcium phosphate (nACP) show promise for reducing enamel alterations while promoting remineralization[28,29].

6.2 Improved Bracket Designs

Innovations in bracket base design are intended to optimize adhesion while minimizing enamel trauma during debonding [4,28].

6.3 Alternative Conditioning Strategies

Phosphoric acid etching remains the gold standard but compromises enamel porosity, making it more stain-prone and caries-susceptible. Ongoing research seeks alternatives that balance bond strength with enamel preservation [28].

6.4 Early Detection and Prevention of Demineralization

Non-invasive diagnostic tools, including scanning electron microscopy, enable earlier and more accurate detection of subsurface demineralization [18]. Preventive and multidisciplinary approaches to managing WSLs during orthodontic treatment are increasingly emphasized [13].

7. Conclusion

Enamel alterations following orthodontic debonding are multifactorial, including roughness, loss of hard tissue, cracks, demineralization, and color changes [30]. Both metal and ceramic brackets present risks, though ceramics generally pose greater threats due to their higher bond strength and brittleness [4].

Future innovations lie in developing adhesives with remineralizing potential, improved bracket designs that facilitate safer debonding, and conditioning strategies that minimize enamel compromise [28]. The ultimate goal remains to achieve effective orthodontic correction with maximum preservation of enamel integrity, ensuring both functional and aesthetic long-term outcomes. Continued research and refinement of clinical protocols will help achieve this balance.

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