DOI: 10.7860/JCDR/2025/76534.22130

Review Article

Dentistry Section

Advancements in Orthodontic Bonding to Non Conventional Surfaces: A Comprehensive Review

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ABSTRACT

Orthodontic bonding traditionally relies on composite resin to adhere brackets to enamel surfaces. However, the emergence of non conventional surfaces, such as ceramic, zirconia and composite materials, presents new challenges due to the increasing demand for aesthetically pleasing orthodontic options and the widespread use of these materials in dental restorations. This review explores recent advancements in orthodontic bonding for non conventional surfaces, evaluating innovative techniques and materials while analysing their effectiveness, reliability and longevity through a critical analysis of bonding protocols. Relevant information was gathered using databases and search engines including PubMed, Scopus and Google Scholar. The present article reviews the materials and techniques used for bonding orthodontic brackets to restorative material surfaces termed non conventional surfaces in contrast to conventional bonding to tooth enamel.

Keywords: Ceramic, Dental restorations, Metal brackets, Resin, Silane

INTRODUCTION

Orthodontic bonding, the cornerstone of modern orthodontic treatment, traditionally involves adhering brackets and other appliances to enamel surfaces using composite resin [1]. However, the emergence of non conventional surfaces, such as ceramic, zirconia and composite materials, has presented unique challenges for orthodontic practitioners [2]. Bonding to these surfaces requires innovative techniques and materials to ensure optimal adhesion and treatment outcomes.

The importance of bonding to non conventional surfaces lies in the increasing demand for aesthetic treatment options and the expanding range of materials used in dental restorations [3]. Patients often seek orthodontic treatment with discreet appliances that blend seamlessly with their natural dentition [4]. Additionally, advancements in restorative dentistry have led to the widespread use of materials like ceramic and zirconia in crowns, bridges and veneers, necessitating orthodontic bonding to these surfaces for coordinated treatment planning [5].

As a result, orthodontic practitioners must adapt their bonding techniques to accommodate these materials, ensuring seamless integration of orthodontic appliances into the overall treatment plan [6]. Coordinated treatment planning is essential to achieve optimal outcomes, emphasising the importance of interdisciplinary collaboration between orthodontists and restorative dentists [7].

The present review explores recent advancements in orthodontic bonding techniques and materials for non conventional surfaces, providing insights into challenges and innovative solutions. Through critical analysis, it evaluates the effectiveness, reliability and longevity of bonding protocols, guiding evidence-based decision-making. By focusing on the evolving landscape of orthodontic treatment, the growing demand for aesthetic solutions and the need for interdisciplinary collaboration, the present review serves as a valuable resource for orthodontists seeking to optimise treatment outcomes on non conventional surfaces.

Bonding of Brackets to Unconventional Surfaces in Orthodontics

In orthodontics, there has been an ongoing endeavour to develop effective techniques for bonding brackets onto various tooth surfaces, particularly in adults [8]. Traditionally, emphasis has been placed on bonding to enamel, especially in the mandibular posterior region, to minimise dental plaque accumulation associated with banding [9,10]. Moreover, band placement is not feasible on fixed bridge units [11]. However, with the evolution and diversification of orthodontic treatments, there is an increasing need to explore bonding methodologies for unconventional surfaces beyond enamel. This has led to the investigation of novel methods for bonding to ceramics, casting alloys, resin composites, dental amalgams and acrylic resins [8].

Ideally, successful bracket bonding to any surface should result in a strong attachment capable of withstanding the forces of orthodontic treatment and mastication without dislodgement, while also ensuring the safety of the surface during debonding after treatment completion [12].

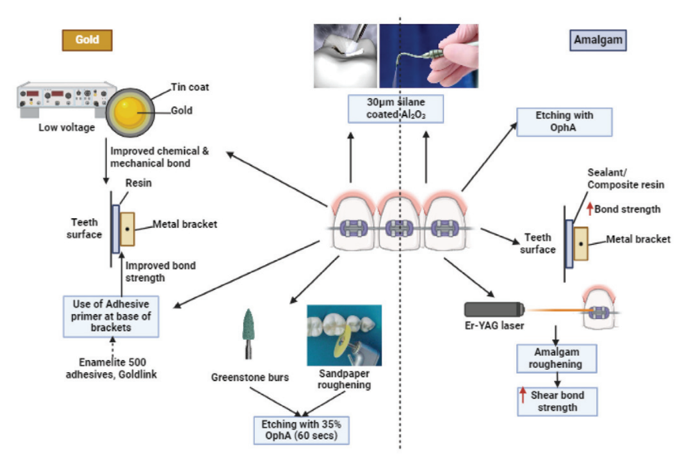
BONDING TO METAL SURFACES

The demand for orthodontic bonding to metal surfaces has increased in recent times. One of the primary challenges is achieving durable adhesion despite the smooth and inert nature of metals. Studies comparing Shear Bond Strength (SBS) on stainless steel crowns using orthodontic adhesives and surface conditioning methods have shown that diamond burs combined with metal primers can achieve a bond strength of 6–8 MPa, providing a viable alternative [13,14]. To overcome this challenge, clinicians utilise various mechanical and chemical surface treatment methods, including air abrasion, sandblasting and the application of etching agents like acid [Table/Fig-1] [13,15].

Gold

Gold is known for its strong integrity, similar to enamel and possesses anti-inflammatory, antibacterial and non toxic properties. However, when used alone, it may experience coating wear-off and exhibit poor orthodontic bond strength [16]. Therefore, proper surface preparation is crucial. In the 1980s, specialised products such as Fusion primers, Enamelite 500 adhesives and Goldlink were introduced for bonding to gold and dental metal alloys [17]. Surface roughening is typically performed using greenstone or sandpaper, followed by etching with 37% Orthophosphoric Acid (OPhA) for 60 seconds [18].

Air abrasion has been considered the preferred method for surface preparation, using 30 µm silane-coated Aluminium Oxide (Al_2O_3).



[Table/Fig-1]: Different ways of bonding orthodontic brackets to gold and amalgam surfaces [13,15].
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[19]. However, surface abrasion with diamond burs and greenstones does not produce a sufficiently rough surface, even under high magnification [20]. This limitation highlights the importance of exploring alternative methods or tools to achieve the optimal surface roughness required for optimal adhesive bonding in dental procedures.

The Food and Drug Administration (FDA) has approved the micro-etcher, the primary micro-sandblaster widely employed for intraoral procedures. The dental chairside variant features a contra-angle nozzle, control buttons and rear-mounted jars holding either fine (50-micron white) or coarser (90-micron tan) Al_2O_3 powder. The tubing is connected to a compressed air supply in the operatory, with an optimal pressure of approximately 7 kg/cm^2.

Alternatively, low-voltage tin plating aids intraoral bonding to noble metals by enabling the deposition of a tin layer on gold surfaces, promoting both chemical and mechanical bonding between resin and metal, thereby significantly enhancing bond strength [21]. Additional methods like electrolytic deposition with devices such as Micro Tin or Kura Ace Mini, or applying a gallium-tin solution with a pure tin bar, also provide options, though they offer only marginal improvements in bond strength [22].

Furthermore, the effectiveness of metal primers on gold surfaces shows variable outcomes. While some studies report poor bonding of metal brackets to gold alloys [23,24], others indicate improved bond strength [16,19,25]. Some authors recommend applying adhesive primer directly to the base of metal brackets for better results. Interestingly, light-curing the resin adhesive for 40 seconds significantly enhances bond strength [25].

Amalgam

Bonding orthodontic brackets to amalgam surfaces presents unique challenges attributable to the composition and properties of amalgam. Typically employed in dental restorations, amalgam comprises a blend of metals including silver, mercury, tin and copper [26]. Its smooth, non porous surface makes adhesive bonding more difficult compared to enamel or other substrates.

Several techniques have been explored to enhance bond strength. Sandblasting amalgam fillings and etching enamel with 37% Orthophosphoric Acid (OphA) may be useful [27-29]. The application of a sealant and bonding with composite resin ensures adequate adhesion [30]. Commonly used resins in orthodontics include Super-Bond D-Liner, Super-Bond Crown & Bridge (C&B) and C&B Meta Bonds [31].

While air abrasion with 50 µm Al_2O_3 powder or surface roughening using diamond burs has been applied, these methods generally yield lower bond strength for amalgam surfaces [32]. The Erbium-doped: Yttrium Aluminium Garnet (Er:YAG) laser effectively removes material from amalgam surfaces, creating crater-like scratches approximately 100 µm in diameter and thereby increasing surface area. Studies have shown that Er,Chromium-doped Yttrium Scandium Gallium Garnet (Cr:YSGG) laser treatment is a viable alternative, achieving higher SBS comparison to air-abrasion methods [33]. Similar studies investigating different surface treatments for bonding to amalgam surfaces are summarised in [Table/Fig-2] [16,29,34,35].

Studies	Objective	Surface treatment	Adhesive	Brackets	Bond strength (Mpa)
Tahmesbi S et al., [34] (2021)	To compare the effect of universal adhesive with the conventional method on Shear Bond Strength (SBS) of orthodontic brackets to amalgam restorations.	G1: Universal adhesive+no surface treatment G2: Universal adhesive+Sandblasting Al_2O_3 G3: Universal adhesive+diamond bur G4: Transbond XT+ no surface treatment G5: Transbond XT+ Sandblasting Al_2O_3 G6: Transbond XT+diamond bur	Scotch-bond Universal adhesive+Transbond XT Adhesive	Mandibular central incisor brackets	G1: 2.30±1.03 G2: 2.48±1.39 G3: 2.29±0.83 G4: 2.76±1.94 G5: 5.49±2.31 G6: 3.81±1.84
Wongsamut W et al, [29] (2017)	Testing of methods to enhance the Shear Bond Strength (SBS) between orthodontic metal brackets and amalgam by sandblasting and different primers.	G1: Tooth G2: Amalgam-No primer+ no sandblasting G3:Amalgam-Alloy Primer (AP)+no sandblasting G4: Amalgam-Metal primer (MP)+no sandblasting G5: Amalgam-Monobond N (MN)+no sandblasting G6: Amalgam-Assure Plus (As)+No sandblasting G7: Amalgam-No primer+ sandblasting G8: Amalgam-Alloy Primer (AP)+sandblasting G9:Amalgam-Metal primer (MP)+sandblasting G10: Amalgam-Monobond N (MN)+sandblasting G11: Amalgam-Assure Plus (As)+sandblasting	Transbond XT	Mandibular incisor brackets	G1: 24.59±3.03 G2: 3.20±0.75 G3: 4.59±0.14 G4: 3.62±0.76 G5: 3.78±0.79 G6: 4.06±0.80 G7: 4.96±0.85 G8: 6.70±1.90 G9: 6.35±1.28 G10: 5.72±1.44 G11: 7.41±1.60
Zachrisson BU et al., [16] (1995)	To compare the effect of different surface treatments and primers on the bond strength of orthodontic brackets bonded to silver amalgam restoration	G1: Sandblasted, Superbond C&B G2: Sandblasted, All-Bond 2 Primers A+B, Concise G3: Sandblasted Geristore G4: Diamond bur, All-Bond 2 Primers A+B, Concise G5: Sandblasted, Concise G6:Sandblasted, Panavia Ex G7: Sandblasted, Scotchbond MP, Concise G8: Concise to etched enamel	Superbond C&B Concise Geristore Panavia Ex Scotchbond MP	Mandibular incisor brackets	G1: 6.4±1.5 G2: 6.3±1.8 G3: 5.5±1.8 G4: 5.3±1.7 G5: 5.0±1.3 G6: 4.5±1.5 G7: 3.4±0.6 G8:13.2± 4.4
Germec D et al., [35] (2009)	To compare, in-vitro, the Shear Bond Strength (SBS) of stainless-steel orthodontic brackets bonded to silver amalgam using three different intermediate resins and two different adhesives and to evaluate bond failure mode.	G1: Amalgam+ Unite+Reliance Metal Primer G2: Amalgam+Unite+Power Bond OLC G3: Amalgam+Resinomer+One-Step Plus (OS+) G4: Enamel+Unite G5: Enamel+Resinomer	Unite Resinomer	Mandibular incisor brackets	G1: 7.15±1.44 G2: 5.99±1.26 G3: 6.41±2.16 G4: 22.11±1.93 G5: 19.46±2.87

[Table/Fig-2]: Similar studies on different surface treatments for bonding on amalgam surfaces [16,29,34,35].

Bonding to Ceramic and Porcelain Surfaces

Ceramic and porcelain are widely utilised in dentistry due to their aesthetic appeal, biocompatibility and durability, particularly in restorations that aim for a natural appearance [36]. However, their smooth texture, lack of porosity and limited mechanical strength pose challenges in orthodontics. Advances in adhesive science and surface preparation methods have facilitated effective bonding to these surfaces. Roughening porcelain surfaces with diamond burs or stones enhances bond strength but may lead to microcracks and fractures in the restoration [9].

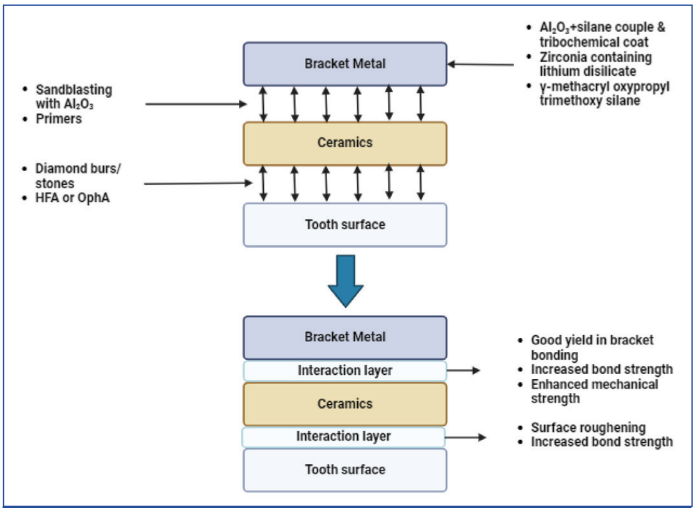
Sandblasting with Al_2O_3 powder is an essential technique for preparing unconventional surfaces in orthodontics for bracket bonding. This method projects fine Al_2O_3 particles onto the surface, creating a rough texture that enhances adhesive retention [37,38]. Studies investigating Al_2O_3 sandblasting on surfaces such as Yttria-Stabilised Tetragonal Zirconia Polycrystal (Y-TZP) ceramic and zirconia have examined SBS with orthodontic metal brackets. Factors including particle size, surface texture and compressive stresses from sandblasting were found to be pivotal in influencing bond strength [39,40]. Additionally, Al_2O_3 powder is biocompatible and inert, ensuring compatibility with dental tissues and minimising the risk of adverse reactions [41].

Air abrasion with Al_2O_3 is also recommended as a surface treatment, as it creates microscopic irregularities that enhance cement retention and ensure orthodontic brackets remain attached to ceramic surfaces. However, it can irreversibly damage ceramics, so powders with particle sizes under 50 μm are preferred [42,43]. Recent studies indicate that using 30 μm Al_2O_3 in combination with silane coupling and tribochemical coating produces robust bonds for brackets on ceramic surfaces [42].

Silane application improves resin composite adhesion to ceramic surfaces by providing reactive sites for both inorganic and organic components. γ-Methacryloxypropyl trimethoxy silane forms siloxane linkages with silanols on the ceramic surface and establishes covalent bonds with the polymer matrix of the resin composite [40]. Recent research has shown that bonding brackets with silane to lithium disilicate Computer-aided Design (CAD) ceramics and zirconia-reinforced lithium silicate glass ceramics yields higher bond strength compared to diamond burs. Additionally, surface treatments with Hydrofluoric Acid (HFA) and ceramic etch and prime further enhance bond strength [44].

The HFA is commonly used for ceramic preparation but should be used cautiously intraorally due to its toxicity [45]. It is typically applied as a 9.6% gel for 2–4 minutes or as a 4% acidulated phosphate fluoride gel with 1.43% HFA for two minutes [46,47]. In challenging cases, a 1.23% acidulated phosphate fluoride gel can be applied for 10 minutes [48]. Etching with 9.6% HFA creates a roughened surface, enhancing bond strength between ceramics and adhesive resins. Furthermore, combining burs with a ceramic primer enhances bracket bonding by removing the glaze and enabling direct interaction with the ceramic surface [49,50].

Kilponen L et al., found that using silane as a primer significantly increased bond strength in ceramic brackets compared to no primer. Although this increase may lead to enamel fractures, it had minimal impact on overall bond strength [51]. A sectional view illustrating the enhancement of ceramic bonding using different approaches is presented in [Table/Fig-3]. Similar studies on various surface treatments for bonding to ceramic and porcelain surfaces are summarised in [Table/Fig-4] [49,50,52-57].



[Table/Fig-3]: Sectional view of the enhancement of ceramic bonding.
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Bonding to Resin Composite-Based Materials

Resin composite-based materials offer favourable aesthetics and versatility but require specific techniques for successful bracket attachment. Surface conditioning is essential for bonding to composite materials, typically involving mechanical roughening using air abrasion, diamond burs, or carbide burs to create microretentive features that enhance adhesive retention [58]. Over time, modifications to composite resins, such as the introduction of bulk-fill, nano-resins and micro-hybrid resins, have reduced undesirable characteristics like polymerisation shrinkage [59].

Advances in adhesive dentistry have addressed these limitations, with Glass Ionomer Cement (GIC) combining the benefits of GIC and composite strength for optimal results. Notable examples of composite materials include Ceram X nano-resin composite and Methacrylate Z350 XT nanocomposite, known for their excellent mechanical and optical properties suitable for anterior and posterior restorations, often used together in a sandwich technique [60]. Additionally, the application of a compatible adhesive primer is crucial to promote chemical bonding between the composite substrate and the adhesive resin [61].

The choice of adhesive system significantly influences bond strength and durability [40]. Self-adhesive resin cements are less effective in achieving a durable bond to zirconia [53]. In a study by Sanli S et al., when preceded by sandblasting, the CC (Crystal Connect, Ivoclar)+Panavia treatment achieved noticeably higher SBS [62]. Light-cured and dual-cured adhesive resins are commonly used in orthodontics, offering rapid polymerisation and flexibility for adequate polymerisation in areas inaccessible to light [63]. These adhesives allow quick bracket placement, minimising chairside time. Dual-cured adhesives provide additional flexibility, ensuring complete polymerisation in areas where light penetration is limited [45].

In recent years, advancements in adhesive technology have led to the development of self-etching primers, which simplify the bonding process by combining primer and adhesive into a single application [64]. These self-etching primers eliminate the need for separate etching and rinsing steps, streamlining the bonding procedure while maintaining reliable bond strength to composite surfaces. Additionally, 37% phosphoric acid acts as a bactericidal agent, enhancing the energy of the dental enamel surface by eliminating non-reactive hydroxyapatite crystals and the acquired pellicle, transforming the surface into highly porous tissue [64].

However, challenges persist in bonding to resin-based materials, particularly regarding long-term bond durability. Resin-based materials, including temporary crown and bridge materials, may exhibit variable surface characteristics that affect adhesive bonding. Proper surface preparation, adhesive selection and clinical technique are paramount to achieving predictable bond strength and minimising the risk of bond failure over time.

Future Direction

Looking ahead, continued advancements in materials science and technology are poised to revolutionise orthodontic bonding to non conventional surfaces. Novel adhesive formulations tailored specifically

Studies	Objective	Surface treatment	Adhesive	Brackets	Bond strength (MPa)
Lee JH et al., [50] (2015)	To compare the Shear Bond Strength between orthodontic metal brackets and glazed zirconia using different types of primer before applying resin cement.	G1) Non glazed +Sandblasting+Zirconia primer G2) Glazing+Sandblasting+etching+Zirconia primer G3) Glazing+sandblasting+etching+porcelain primer G4) Glazing+sandblasting+etching+zirconia primer+porcelain primer	Transbond XT light cured composite	Mandibular incisor metal brackets	G1: 13.7±1.3 G2: 3.7±0.9 G3: 16±2.6 G4: 14.4±1.7
Kwak JY et al., [49] (2016)	To evaluate the effects of different surface conditioning methods on the bond strength of orthodontic brackets to glazed full-zirconia surfaces	G1 - unglazed): Silicon carbide paper roughening G2) Diamond bur +Z-prime plus primer G3) Pumice+Monobond-S primer G4) 4% Hydrofluoric Acid (HFA)+Monobond-S primer G5) Sandblasting (Al_2O_3)+Monobond-S primer G6) Sandblasting (Al_2O_3)+Z-prime plus primer G7) Sandblasting (SiO_2)+Monobond-S primer	Transbond XT light-cure composite resin	Mandibular incisor metal brackets	G1: 13.38±2.57 G2: 15.48±3.15 G3: 14.90±2.75 G4: 15.24±3.36 G5: 15.78±2.39 G6: 4.60±1.08 G7: 14.81±2.91
Yassaei S et al., [52] (2015)	To evaluate the effect of four zirconium surface treatment methods on Shear Bond Strength (SBS) of orthodontic brackets.	G1) 9.6% Hydrofluoric Acid (HFA)+silane primer G2) Sandblasting (Al_2O_3)+Silane primer G3) Er:YAG laser (1W)+Silane primer G4) Er:YAG laser (2W)+Silane primer	Light-cured composite resin	Metallic maxillary central incisor brackets	G1: 5.8±0.78 G2: 7.8±1.02 G3: 6.8±0.92 G4: 6.9±1.13
Amer JY and Rayyan MM [53] (2018)	To evaluate the effect of different surface treatments and bonding modalities on the Shear Bond Strength (SBS) between metallic orthodontic brackets and zirconia crowns.	G1) No surface treatment G2) Sandblasting G3) Soflex disc	i) Clearfil ceramic primer+Panavia F 2.0 adhesive resin cement ii) Rely X U200 self adhesive resin cement	Lower second premolar metal brackets	Clearfil+Panvia F 2.0: G1: 0 G2: 20.8±4.8 G3: 12.3±2.8 Rely X U200: G1: 0 G2: 16.7±4.6 G3: 11.6±3
Lee JY al., [54] (2018)	To compare the Shear Bond Strengths (SBS) of ceramic brackets bonded to zirconia surfaces using different zirconia primers and universal adhesive.	G1) Sandblasting G2) Sandblasting+Metal/ Zirconia primer G3) Sandblasting+Z-Prime plus G4) Sandblasting+Zirconia liner G5) Sandblasting+Scotchbond universal adhesive	Transbond XT primer+Transbond XT light cured composite	Ceramic brackets	G1: 1.07±0.81 G2: 5.16±0.83 G3: 10.47±2.89 G4: 9.55±1.75 G5: 13.85±1.48
Cetik S et al., [55] (2019)	To compare the Shear Bond Strength (SBS), the amount of adhesive remaining on the material's surface, the incidence of adhesive, cohesive and mixed failures and the occurrence of zirconia fractures.	G1) Sandblasting+Silane primer G2) Er:YAG laser+Silane primer	Brack Fix primer+Brack 1Fix light cured composite	i)Mandibular anterior metal brackets ii)Mandibular anterior ceramic brackets	Metal brackets: G1: 23.29±5.34 G2: 21.59±4.03 Ceramic brackets: G1: 20.06±4.05 G2: 17.55±3.88
Mehmeti B et al., [56] (2019)	To analyse Shear Bond Strength (SBS), Adhesive Remnant Index (ARI) and Porcelain Fracture Index (PFI) of ceramic and metallic orthodontic brackets bonded to zirconia or lithium-disilicate ceramics conditioned with Hydrofluoric Acid (HFA) or phosphoric acid (PhA).	G1) 37% phosphoric acid for 120 s+silane primer G2) 5% Hydrofluoric Acid (HFA)+silane primer	Transbond XT primer+Transbond XT light-cure composite	i) Metal brackets ii) Polycrystalline ceramic brackets	Metal brackets: G1: 10.85±5.84 G2: 8.52±4.72 Ceramic brackets: G1: 11.84±7.30 G2: 8.99±5.36
Akay C et al., [57] (2020)		G1) Er:YAG laser (2W) G2) Nd:YAG laser (2W) G3) Sandblasting (SiO2) G4) 9.6% Hydrofluoric Acid (HFA)	Transbond XT light-cured composite	Maxillary central incisor metal brackets	G1: 5.5±0.79 G2: 4.88±0.82 G3: 7.42±0.92 G4: 3.58±0.75

[Table/Fig-4]: Similar studies on different surface treatments for bonding on ceramic and porcelain surfaces [49,50,52-57].

for diverse substrate types, including ceramics and composite materials, are expected to offer enhanced bond strength, durability and biocompatibility. With a growing emphasis on personalised orthodontic treatment, the development of adhesive systems capable of adapting to individual patient characteristics, such as enamel quality and oral microbiome composition, holds promise for optimising treatment outcomes and minimising adverse effects.

Furthermore, the integration of digital technologies, such as 3D scanning and CAD, is expected to streamline bracket placement and improve precision, reducing chairside time and enhancing patient comfort. Collaborative efforts between orthodontists, materials scientists and engineers are likely to yield innovative bonding techniques that mitigate common challenges associated with non conventional surfaces, such as poor retention and susceptibility to plaque accumulation. Advancements in surface modification techniques, such as plasma treatment and nanotechnology, may further enhance the adhesive properties of orthodontic brackets, facilitating secure attachment and long-term stability. As the demand for minimally invasive and aesthetically pleasing orthodontic treatments continues to rise, the pursuit of cutting-edge bonding methodologies tailored to non conventional surfaces is poised to shape the future of orthodontics, ushering in an era of personalised, efficient and patient-centric care.

CONCLUSION(S)

Orthodontic bonding to non conventional surfaces, like ceramics, zirconia and resin composites, presents unique challenges and opportunities in modern orthodontic treatment. The demand for aesthetic options and interdisciplinary collaboration with restorative dentistry underscores the importance of adapting bonding techniques to accommodate these materials. Through recent advancements in adhesive technology and surface modification techniques, orthodontists can achieve optimal adhesion and treatment outcomes on non conventional surfaces. However, challenges such as bond durability and material compatibility persist, emphasising the need for evidence-based decision-making and continuous innovation in orthodontic bonding. Interdisciplinary collaboration between orthodontists and restorative dentists is crucial for coordinated treatment planning and achieving optimal results. Furthermore, effective patient communication and management are vital to ensure patient understanding, cooperation and satisfaction throughout the treatment process.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Nov 02, 2024
- Manual Googling: May 12, 2025
- iThenticate Software: Jul 07, 2025 (7%)

DENTISTRY: Author Origin

EMENDATIONS: 7

AUTHOR DECLARATION:
- Financial or Other Competing Interests: None
- Was informed consent obtained from the subjects involved in the study? No
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: **Nov 01, 2024**
Date of Peer Review: **Feb 27, 2025**
Date of Acceptance: **Jul 09, 2025**
Date of Publishing: **Dec 01, 2025**