

Orthodontic Bonding to Full Ceramic Restorations: Material-Specific Surface Preparation Strategies: A Narrative Review

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Abstract

The increasing number of adults receiving orthodontic treatment has made bonding to pre-existing ceramic restorations a routine clinical challenge. The objective of this narrative review is to explain how ceramic composition determines surface conditioning and to translate the available evidence into material-specific protocols for orthodontic attachment bonding. Glass-matrix ceramics contain a silica-rich phase that can be selectively etched with hydrofluoric acid and chemically coupled with silane. Polycrystalline ceramics, particularly zirconia, lack an etchable glass phase; therefore, airborne-particle abrasion or tribochemical silica coating combined with a phosphate-monomer primer is generally more appropriate. Resin-matrix ceramics require a conservative protocol selected according to their ceramic and polymer content. Laser conditioning can increase surface roughness, but results depend strongly on the ceramic, wavelength, energy, and irradiation settings; excessive energy may cause microcracking, thermal damage, or phase transformation. Across ceramic groups, the goal is not to maximize bond strength, but to obtain a durable bond that tolerates orthodontic loading and still permits safe debonding without damaging the restoration. Current evidence remains dominated by laboratory studies with heterogeneous ageing and testing methods. Clinicians should first identify the ceramic, use the least destructive effective pretreatment, add the appropriate chemical coupling agent, and follow material- and manufacturer-specific instructions.

Keywords: Ceramics; Hydrofluoric Acid; Orthodontic Bonding; Silane; Surface Treatment; Zirconia.

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INTRODUCTION

The growth of adult orthodontics has increased the frequency with which brackets, buttons, and tubes must be bonded to restorations rather than intact enamel. All-ceramic crowns and veneers are especially relevant because they combine high esthetic value with surface chemistries that differ fundamentally from enamel and from one another. [1,2] A protocol that performs well on feldspathic porcelain may be ineffective or damaging on zirconia. Consequently, the generic instruction to "bond to porcelain" is no longer sufficiently precise for contemporary practice.

The clinical objective is a bond that resists treatment forces and oral ageing but can be removed without chipping, cracking, or irreversibly roughening the restoration. Bonding outcome is influenced by ceramic composition, glaze, surface contamination, mechanical pretreatment, chemical coupling, adhesive selection, bracket design, and ageing conditions. [3-5]

Very high laboratory bond values are not automatically desirable if failure occurs within the restoration at debonding. This review condenses the ceramic science and orthodontic bonding literature into a material-specific clinical framework, with emphasis on hydrofluoric acid etching, air abrasion, tribochemical silica coating, laser conditioning, silanes, and phosphate-monomer-containing adhesives.

METHODS

This manuscript was developed as a focused narrative review. The planned concept blocks were orthodontic attachment or bracket bonding; ceramic, porcelain, glass ceramic, lithium disilicate, zirconia, alumina, or hybrid ceramic; and surface treatment, hydrofluoric acid, air abrasion, tribochemical silica coating, laser, silane, 10-MDP, universal adhesive, bond strength, or debonding. Original laboratory and clinical studies, systematic reviews, and key materials-science papers directly informing orthodontic bonding were eligible. Prosthodontic luting studies were considered

only when they clarified ceramic surface chemistry or durability. Evidence was extracted by ceramic class, pretreatment, coupling agent, adhesive, ageing method, bond outcome, failure mode, and reported surface damage, then synthesized thematically. Because this is a narrative review and the underlying methods were heterogeneous, no meta-analysis or formal pooled estimate was attempted.

CERAMIC COMPOSITION DETERMINES THE BONDING STRATEGY

A clinically useful classification separates glass-matrix, polycrystalline, and resin-matrix ceramics.[3] Glass-matrix materials include feldspathic porcelain, leucite-reinforced ceramics, and lithium-disilicate glass ceramics. Their silica-rich vitreous phase can be selectively dissolved to create microporosities and can react with silane. The proportion and distribution of glass and crystals determine how readily a material is etched. Etching time and acid concentration therefore cannot be transferred indiscriminately between products.

Polycrystalline ceramics such as zirconia and alumina have little or no glass phase. Hydrofluoric acid does not create a predictable retentive pattern on these oxides. Retention must instead be generated by controlled mechanical modification, followed by chemical interaction with functional monomers. Zirconia is strong, but aggressive grinding, high-pressure abrasion, or excessive laser energy can introduce defects or alter its surface phase. [6,7] Resin-matrix ceramics contain both an inorganic network and a polymer phase; their response varies with formulation, so the manufacturer's surface-treatment instructions are particularly important. The first clinical decision is therefore to identify the restoration accurately from records, product information, or communication with the restorative clinician.

The surface encountered clinically may not represent the bulk material. A feldspathic veneering layer can cover a zirconia framework, and a highly polished, stained, or glazed surface may mask the reactive phase beneath it. Conditioning the visible veneering ceramic as though it were monolithic zirconia, or conversely applying HF to exposed zirconia, can produce an ineffective interface. Glaze improves esthetics and smoothness but offers limited micromechanical retention; when removal is necessary, it should be confined to the bracket footprint and performed with a method that does not propagate cracks. Contemporary zirconias also vary in yttria content, translucency, grain structure, and transformation behavior. These differences reinforce the need to record the exact restoration whenever possible rather than treating all zirconias as a single substrate.

MICROMECHANICAL SURFACE PREPARATION Hydrofluoric acid etching

Hydrofluoric acid (HF) selectively dissolves the silica-rich glass phase, exposing the crystalline structure and creating a high-energy microporous surface for resin penetration.[8] For silica-based ceramics, HF followed by silane has repeatedly produced clinically useful orthodontic bond strengths. [9-12] The response, however, depends on composition, acid concentration, application time, glaze, rinsing, and subsequent coupling. Prolonged or overly concentrated etching can weaken the superficial ceramic and produce deep defects. Because HF can cause severe soft-tissue injury, intraoral use requires meticulous isolation, controlled application, high-volume evacuation, thorough rinsing, and adherence to the product instructions. If safe isolation cannot be assured, a non-HF alternative should be selected. HF should not be used to condition zirconia or alumina because these ceramics do not contain an etchable glass phase.

HF treatment is only the micromechanical component of the interface. After etching, incomplete rinsing can leave reaction products that interfere with wetting, whereas desiccation or surface contamination can reduce coupling. Silane should follow promptly once the etched surface is clean and dry. Etching through an intact glaze is less predictable than exposing and conditioning the underlying glass ceramic. For thin laminate veneers, every additional surface-removal step must be weighed against the risk of reducing thickness or creating a defect that becomes clinically relevant during bracket removal.

Airborne-particle abrasion and tribochemical silica coating

Air abrasion uses alumina particles to remove glaze or contaminants and to create irregularities that increase wettable surface area. Its effect is governed by particle size, pressure, distance, duration, and ceramic thickness. Moderate protocols can improve bonding, whereas aggressive abrasion may create stress concentrators and compromise thin veneers. [6,13] On glass ceramics, air abrasion is generally an alternative or adjunct when HF is contraindicated rather than a universal replacement for HF-silane conditioning. On zirconia, low-pressure abrasion is a common mechanical step because acid etching is ineffective. [5-7,14,15]

Tribochemical silica coating propels silica-modified alumina particles onto the surface. The impact roughens the substrate and deposits a silica-rich layer, allowing subsequent silane coupling. This can be useful for oxide ceramics, but results depend on the coating protocol and ageing; it should not be assumed to be equivalent to every alumina-abrasion regimen. After any airborne-particle treatment, the surface must be cleaned without introducing phosphate or salivary contamination before the chemical primer is applied.

Comparisons between abrasion studies require caution. Nominally similar protocols may differ substantially in particle velocity, nozzle design, incidence angle, and whether a glazed or previously polished surface was tested. Bond-strength gains observed immediately after abrasion may diminish after water storage or thermocycling if chemical coupling is absent. Accordingly, mechanical roughening should be viewed as preparation for a durable chemical interface rather than as a complete bonding strategy by itself.

Laser conditioning

Er:YAG, Er, Cr:YSGG, Nd:YAG, CO₂, and other lasers have been investigated as contact-free alternatives to acids and particle abrasion. Laser irradiation may create pits, grooves, and microretentive areas, but the balance between useful ablation and damage is narrow and material-specific.[16,17] Systematic and integrative reviews report that lasers often improve bond strength compared with untreated controls, yet they are not consistently superior to established abrasion or HF-based protocols.[16,17]

On zirconia, Er:YAG and Nd:YAG studies have produced conflicting results; higher energy may increase roughness without improving durable adhesion and may generate microcracks, melting, or phase changes.[18,19] On feldspathic porcelain and laminate veneers, selected Er:YAG or Nd:YAG settings have achieved bond strengths comparable with HF in some studies,[20-22] while other investigations found laser-only groups inferior to HF or combined conditioning.[23,24] The evidence does not support a single transferable laser setting. Lasers should therefore be considered a parameter-sensitive alternative or adjunct, not a default protocol, and should be used only when the clinician can match the wavelength and settings to the specific material and supporting evidence.

The numerical results illustrate this parameter sensitivity. In laminate veneer specimens, Aksakalli *et al.*[20] reported mean shear bond strengths of 10.8 MPa after HF and 9.3 MPa after Er:YAG irradiation, with no major structural damage identified by surface analysis. Hosseini *et al.*[21] observed a progressive rise in feldspathic porcelain bond strength as Nd:YAG power increased, with higher settings approaching the HF group. By contrast, combined-treatment and laser-only comparisons have also shown substantially lower results for laser-only conditioning.[23] These studies cannot define a universal clinical dose because they used different ceramics, lasers, specimen geometries, and ageing regimens. They instead show why the complete parameter set must be reported and why extrapolation between devices is unsafe.

CHEMICAL COUPLING

Silanes

Silanes are bifunctional coupling agents. Hydrolysable groups interact with hydroxylated silica at

the ceramic surface, while the organofunctional group copolymerizes with methacrylate resin. Their benefit is therefore greatest on silica-containing ceramics after the glass phase has been exposed. [25,26] Silane does not compensate for an intact, nonreactive glaze or for inadequate cleaning. A thin, fresh layer should be applied to a clean and dry surface and allowed to react and evaporate according to the manufacturer. Silane alone is unreliable on untreated zirconia because the required silica-rich substrate is absent.

Silane layers are sensitive to hydrolysis and storage conditions. Excessively thick or incompletely evaporated silane can leave a weak interphase, while aged single-bottle products may be less reactive. Gentle air drying after the prescribed reaction time promotes solvent evaporation and a thin coupling layer. Although some universal adhesives include silane, the acidic and aqueous environment of a multi-component bottle may limit long-term silane stability; a separate fresh silane remains a rational choice when bonding to an HF-etched glass ceramic and when permitted by the adhesive system.

Phosphate monomers and universal adhesives

The functional monomer 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) can form chemical interactions with metal oxides and is central to zirconia bonding. MDP-containing primers or universal adhesives are most effective when combined with an appropriate mechanical treatment and a compatible resin.[7,27] Laboratory syntheses generally support this combined strategy, although durability varies with product composition, contamination, and ageing.[15,28] Universal adhesives may contain MDP, silane, or both, but the presence of multiple components does not make them interchangeable with every dedicated primer. A recent systematic review concluded that universal adhesives can simplify orthodontic bonding across substrates, while ceramic performance still benefits from substrate-specific HF etching and/or sandblasting.[29] Studies of all-ceramic materials similarly show that universal adhesives work best when the underlying surface has first been conditioned for its material class.[30]

For zirconia, MDP performance also depends on access to a clean oxide surface. Salivary phosphates and residues from try-in procedures may compete for reactive sites, and conventional phosphoric-acid cleaning is not automatically beneficial. Cleaning should therefore follow the zirconia and primer manufacturers' recommendations. The orthodontic resin must also be compatible with the primer or universal adhesive; simplified product combinations can introduce incompatibility between acidic monomers and chemically cured components. Using a validated same-system combination reduces avoidable uncertainty.

CERAMIC-SPECIFIC CLINICAL PROTOCOLS

Glass-matrix ceramics

For feldspathic, leucite-reinforced, and lithium-disilicate ceramics, the most evidence-supported sequence is accurate material identification, isolation, conservative glaze removal when needed, manufacturer-specified HF etching, copious rinsing and drying, silane, and resin-based orthodontic adhesive.[5,8-12] The clinician should not apply a single HF time to all glass ceramics: crystal content and manufacturer recommendations differ. When HF is contraindicated, controlled air abrasion or an evidence-based laser protocol may provide an alternative, but the expected bond and the risk to thin restorations should be considered. At debonding, the objective is cohesive failure within the adhesive rather than within the ceramic.

When the precise glass ceramic is unknown, the operator should avoid selecting an etching time from appearance alone. Restorative records, radiographs, the treating dentist, or the laboratory may clarify whether the surface is feldspathic porcelain, lithium disilicate, a veneering ceramic, or another material. A small, well-isolated bracket footprint and careful documentation make subsequent replacement or polishing more predictable.

Zirconia and other oxide ceramics

Zirconia should not be etched with HF. A practical sequence is cleaning, conservative low-pressure alumina abrasion or tribochemical silica coating, removal of debris, application of an MDP-containing primer or compatible universal adhesive, and bonding with a resin-based orthodontic adhesive.[5-7,15,27-29] If tribochemical silica coating is used, silane may be added because the deposited silica enables siloxane coupling. Abrasion pressure and duration should be limited, especially on thin or highly translucent zirconia. Surface contamination after try-in or isolation failure can impair the phosphate-monomer interaction and must be addressed before priming. Laser pretreatment may be considered only when a validated zirconia-specific protocol is available; it is not a predictable substitute for abrasion plus MDP.

Resin-matrix and hybrid ceramics

Because these materials combine ceramic fillers or networks with a resin phase, treatment should follow the named product rather than a broad "ceramic" label. Conservative abrasion or bur roughening may expose the substrate, followed by a compatible universal adhesive or separate silane/MDP strategy based on composition. Excessive HF can degrade resin-rich surfaces, and unnecessary aggressive abrasion can remove substantial material. Product instructions and direct communication with the restorative team are the safest basis for selection.

Table 1: Material-specific clinical framework for orthodontic bonding to ceramic restorations

Ceramic group	Mechanical conditioning	Chemical coupling	Caution
Glass-matrix: feldspathic or leucite-reinforced ceramic	Conservative glaze removal if required; manufacturer-specified HF etching	Silane, then resin adhesive	HF safety is critical; avoid over-etching and protect thin veneers
Glass-matrix: lithium disilicate	Manufacturer-specified HF etching; do not copy feldspathic etching time	Silane, then resin adhesive	Crystal content changes etching response; follow the named product
Zirconia or alumina	Low-pressure alumina abrasion or tribochemical silica coating	MDP primer/universal adhesive; add silane after silica coating	HF is ineffective; avoid aggressive abrasion and contamination
Resin-matrix or hybrid ceramic	Conservative abrasion/bur roughening according to product instructions	Compatible universal adhesive or composition-specific primer	Avoid assuming every hybrid ceramic behaves like glass ceramic

HF: hydrofluoric acid; MDP: methacryloyloxydecyl dihydrogen phosphate. The table is a decision framework, not a substitute for the instructions of the named ceramic, primer, and adhesive. Table word count: 106.

CLINICAL IMPLICATIONS, DEBONDING, AND EVIDENCE GAPS

A short pre-bonding checklist prevents many failures: identify the ceramic; inspect the restoration for cracks or thin margins; obtain informed consent regarding possible surface alteration; isolate the field; choose the least destructive effective pretreatment; match silane to silica-containing ceramics and MDP to oxide ceramics; and document every product, concentration, setting, and time. The bonding target should be sufficient retention with a planned safe removal pathway, not the highest possible shear bond strength. During debonding, controlled force,

magnification, and careful resin cleanup reduce the risk of ceramic fracture and unnecessary surface loss. Polishing should restore a smooth surface without thinning the restoration. [2,31]

Bracket base and adhesive handling remain relevant after the ceramic has been conditioned. The attachment should be seated with uniform pressure, excess resin should be removed without scratching the restoration, and curing should account for the opacity and thickness of both bracket and ceramic. At failure analysis, the adhesive remnant index can help distinguish inadequate ceramic coupling from excessive adhesion to

the restoration. Rebonding should begin with reassessment of the failure surface rather than automatic repetition of the original protocol, because residual resin, exposed ceramic, and newly created roughness alter the substrate.

The evidence base is limited mainly by in vitro designs, inconsistent ceramic naming, variable surface protocols, different bracket bases and adhesives, and nonuniform storage, thermocycling, and mechanical testing. Immediate shear bond strength may not predict clinical survival or safe debonding. Future research should report the exact ceramic generation, glaze status, pretreatment parameters, contamination control, ageing regimen, failure mode, and surface damage. Prospective clinical studies are particularly needed for contemporary translucent zirconias, universal adhesives, and laser-assisted protocols. Until stronger clinical evidence is available, material-specific, conservative combination protocols are more defensible than universal one-step claims.

A minimum reporting set would improve comparability: commercial name and composition of the ceramic; whether the tested surface was glazed, polished, or sectioned; particle, acid, or laser parameters; primer and adhesive chemistry; specimen storage; thermocycling and mechanical ageing; loading mode and crosshead speed; bond strength with dispersion; failure mode; and microscopy-based assessment of restoration damage. Clinical investigations should additionally report attachment survival, timing and cause of failure, chairside repair, debonding complications, and the final surface quality perceived by the patient and restorative clinician.

CONCLUSION

Orthodontic bonding to all-ceramic restorations requires identification of the substrate before surface treatment. For glass-matrix ceramics, controlled HF etching followed by silane and a resin adhesive remains the reference strategy when safe isolation is possible. For zirconia and other oxide ceramics, conservative mechanical roughening combined with an MDP-containing primer or compatible universal adhesive is more appropriate. Resin-matrix ceramics require product-specific conditioning. Lasers may be useful in selected circumstances, but their effects are highly parameter-dependent and they are not a universal replacement for established protocols. The most clinically responsible approach is the least destructive protocol that provides durable retention and preserves the restoration at debonding.

DECLARATIONS

Conflicts of Interest: The authors declare no conflicts of interest.

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