Journal of Dentistry and Oral Biology

Review Article
Published: 22 Jun, 2017

Resin Composites in Orthodontic Bonding. A Clinical Guide

*Kotrogianni M and Rahiotis C**

Department of Operative Dentistry, National Kapodistrian University of Athens, Greece

Abstract

Orthodontic brackets are cemented either to labial or to lingual tooth surfaces acting as a medium for the delivery of forces applied by the arch wire and auxiliaries on the teeth. Among the factors contributing to the success of this procedure, the adhesive cements play a significant role. The adhesive cements used in order to bond brackets to dental surfaces are glass ionomer cements, resin modified glass ionomer cements and composite resins. Composite resins are gaining more and more ground in everyday orthodontic practice, due to their constantly improving physic-mechanical properties, handling characteristics and due to the simultaneous improvement of curing units, etching and bonding factors. The purpose of this literature review is the presentation of an update on the use of resin composites in orthodontic bracket bonding in dental surfaces, according to data based on the results of both laboratory and clinical studies.

Keywords: Composite resins; Orthodontic brackets; Debonding; Rebonding

Introduction

Orthodontic brackets are cemented either to labial or to lingual tooth surfaces acting as a medium for the delivery of forces applied by the arch wire and auxiliaries on the teeth. The factors which are the main contributors for the successful transfer of orthodontic forces on tooth include the surface preparation of the bonded enamel surface, the type of adhesive cement used, the material as long as the surface finish of the bracket [1-3].

Among these aforementioned factors, the adhesive cements play a key role in this procedure. The ideal cement used for orthodontic bracket bonding should exhibit enough retention to resist displacement during normal oral function and transmit the required orthodontic forces on the tooth itself. Furthermore, it should be easily removed once the treatment is complete, without causing any damage to the tooth surface and, ideally, without leaving residues, which need to be removed by drilling or air abrasion [4].

The most commonly used adhesives in order to bond brackets to teeth are composite resins, glass ionomer cements (GICs) and resin modified glass ionomer cements (RMGICs). Nowadays, the resin composites have gain increased popularity among the Orthodontists due to improved physic-mechanical properties and handling characteristics. Composite resins use the micromechanical retention of an acid-etched enamel surface and they require the application of a suitable primer/bonding agent in order to facilitate a bond between the two surfaces.

The purpose of this literature review is the presentation of an update on the use of resin composites in orthodontic bracket bonding in dental surfaces, according to data based on the results of laboratory and clinical studies.

Composite Resins

Since Buonocore [5] introduced the acid etch bonding technique in 1955, the concept of bonding various resins to enamel has developed applications in all fields of restorative dentistry, including orthodontic brackets bonding [6]. In 1968, Newman was the first, who tried to bond orthodontic brackets to enamel teeth surfaces using the acid etch technique and an epoxy-derived resin [7]. Acid-etching and a bis-phenol A glycidyl methacrylate (Bis-GMA) resin was first used for direct bonding of orthodontic brackets by Weisser [8] and Silverman et al. [9]. Since the Bis-GMA resins were first applied in clinical orthodontic practice as adhesives, the acid-etched/composite technique has become the most widely adopted bonding system in contemporary orthodontic practice, resulting in many advantages, such as simple handling, good adhesion, reduced gingival irritation, improved

***Correspondence:**
Chris Rahiotis, Department of Operative Dentistry, National Kapodistrian University of Athens, Thivon 2, Goudi, 11527, Greece,
E-mail: craxioti@dent.uoa.gr

Received Date: *25 Apr 2017*
Accepted Date: *11 Jun 2017*
Published Date: *22 Jun 2017*

Citation:
Kotrogianni M, Rahiotis C. Resin Composites in Orthodontic Bonding. A Clinical Guide. J Dent Oral Biol. 2017; 2(7): 1054.

ISSN: 2475-5680

aesthetics and reduction in caries [10,11].

When phosphoric acid is applied to the enamel, a selective dissolution of the hydroxyapatite crystals occurs, leading to microporosities throughout its surface [12]. The enamel loss during etching is estimated to be 10 μm to 30 μm [13]. When the fluid monomers of the composite resin infiltrates into the porous enamel and polymerized, a micromechanical bond is achieved between the resin and the tooth surface, similar to the one between the resin and the orthodontic bracket [14].

The first and most popular bonding resins were chemically curing. A major drawback of such a system was the fact that the practitioner did not have the chance to manipulate its handling time [15]. Moreover, chemical curing composites require mixing of two pastes, which could induce the incorporation of air bubbles into the material, leading thus to lower mechanical properties [16]. The use of light-cured resins for orthodontic bonding was first described in 1979 *in vitro* [17]. In the direct bonding technique the material is cured under metal-based or ceramic brackets by direct illumination from different sides and by transillumination, since the tooth structure has the ability to transmit the visible light. The application of visible light acts as a command set for the onset of the polymerization, resulting in enough working time, allowing the clinician to place the brackets properly and remove the excesses on time. The composite resins currently available allow different types of activation; light cured, chemically cured or dual cured [18].

The composition of orthodontic composite resins is very similar to that of those used in restorative dentistry. They consist of an organic matrix (Bis-GMA, TEGMA), initiators and an inorganic filler content, which occupy approximately 77% of their total weight. The filler content is responsible for the increase of the mechanical properties of the material, such as strength and wear resistance [19]. The fact that their composition is similar to that of the composite resins used in restorative dentistry has led to the indication of low-viscosity flowable composites for bracket bonding instead of orthodontic composite [20-22]. They merit great attention because of two of their clinical handling characteristics, such as non-stickiness and fluid injectability [23]. Their high fluidity could be an advantage for bracket bonding, since a better adaptation in areas of anchorage and regions of demineralized enamel is allowed [24]. In addition, flowable composites are usually less expensive than orthodontic composites [25] and their low modulus of elasticity could act as an "elastic layer" [26], preventing stress concentration at the tooth/bracket interface during light-activation and providing a better allocation of the stresses generated during occlusal movements [27]. Besides low-viscosity composite resins, resin cements are also being used lately as an adhesive to bond brackets to enamel surface. Light curing units used, the most light-cured resin composites use camphoroquinone as a photoinitiator, which is sensitive to light in the blue region of the visible light spectrum, with pick absorption at approximately 470 nm. Once the light reaches the resin surface, free radicals generated, initiating the polymerization process [28,29].

TQH units

Tungsten-quartz halogen curing units (TQH) have been conventionally used as the source of visible light. TQH is an incandescent lamp which produces a broad spectral emission. Most of the emission is actually infrared irradiation that generates heat, which be harmful to the dental tissues [30], and leads to overheat of the device itself [31]. Because of all the heat generation the power loss of the TQH reaches 70%, when at the same time, less than 1% of the electrical energy is used for light emission. Moreover, the light intensity decreases approximately 10% when a filter is used to reduce infrared irradiation and obtain the optical wavelength range required for curing the composite resins [32,33]. Another main disadvantage of TQH is that halogen bulbs have a limited effective lifetime of around 100 hours, above which their energy output gets more and more decreased. TQH units deliver intensity which ranges 400 mW/cm^2 to 1,200 mW/cm^2. In order to achieve adequate polymerization a 40 sec light curing time per site is required [34,35], which means that the total light curing time approaches 15 min. Fifteen minutes time is too long for both the orthodontist and the patient. In order to overcome some of these disadvantages, modifications have been performed, such as the increase of the light intensity, by the use of improved light guides [36-38].

PAC units

As an alternative for rapid light curing, the plasma arc curing unit (PAC) was introduced in the late 1990s. PAC uses a high-frequency electrical field to generate plasma energy. More specifically, two electrodes are used in order to transform xenon gas into a mixture of ions, electrons and molecules, releasing a significant amount of energy as plasma. PAC produces high intensity lights delivering up to 2,000 mW/cm^2 and the light can be filtered to a narrow bandwidth concentration of 450 nm to 500 nm for peak absorption by camphoroquinone [39]. An irradiation time of 6 sec to 9 sec is sufficient in order to achieve an adequate resin polymerization, equal to that achieved by a 40 sec exposure of a conventional TQH [40,41]. Their lifespan is up to 5,000 hours. However, PAC units have several disadvantages, such as their high purchase cost, their relatively large size and their complex construction [42].

LED units

Light curing units with gallium nitride blue light emitting diodes (LED) have also been developed [43]. Their spectral output falls within the absorptive region of camphoroquinone, which means that no filters are required for the production of blue light. LEDs incorporate two connected solid semiconductors with an electric charge supplied from a battery. Their spectrum flux is concentrated over a much narrower bandwidth than that of TQH or PAC [44-46]. Energy is released almost exclusively as light energy, generating minimal heat. LEDs have many advantages compared to TQH or PAC such as a lifetime over 10,000 hours, invariable output energy over this term without any degradation and suitability for portable use because of their small size, low energy consumption and high resistance against shock or vibration. They produce between 410 nm to 500 nm. Advances in the power output of LEDs have allowed LEDs to achieve emission intensity up to 1,600 mW/cm^2, decreasing even more the curing time. The curing time per bracket for a LED unit is estimated to be 9 sec to 10 sec.

Several *in vitro*, *in vivo* studies and systematic reviews have been conducted, comparing the performance of the three light curing systems. In 2008, Koupis et al. [45] conducted a study focused on the failure rate of two polymerization sources, a TQH lamp (Ortholux XT lamp, 3M, USA) and a LED lamp (Ortholux LED, 3M, USA). Although the overall failure rate recorded with the halogen unit was not significantly different than the one recorded with the LED unit, the duration of the polymerization with the halogen lamp was twice as long as that with the LED unit. Mean failure risks identified for each polymerization system are comparable: 4.3% to 5.8% for halogen units, 5.3% for plasma arc and 4.3% for LED units. In 2010, Retamoso et al. [47] conducted a similar search, comparing the shear bond strength of brackets bonded with an orthodontic composite resin, Transbond (3M, USA), and light cured either with a halogen light device (Ortholux XT lamp, 3M, USA) or a LED device (Ortholux LED, 3M, USA). Although the light curing units did not influence at all the shear bond strength, the use of the LED device reduced the experimental time by approximately 60%, with the same curing efficiency as the halogen device. Both halogen and LED curing units seem to provide comparable shear bond strengths, when bonding orthodontic brackets [48]. However, the light intensity of LED units seems to decrease with distance, consulting into lower shear bond strengths [49]. According to the study of Cacciafesta et al. [50] in 2005, using the LED light, a greater light-tip distance produced significantly lower shear bond strength values, whereas using the plasma arc lamp, a greater light-tip distance caused significantly higher shear bond strength values. The decrease in power output, leading to lower shear bond strength values, started when the LED curing unit was placed at a light-tip distance of 6 mm. The halogen light showed no significant differences among the different distances.

According to a survey of 2010, the light source of choice among the orthodontists in the United States seems to be the LED curing unit (64.1%), probably due to the reduced chair timing it provides. The second unit of choice seems to be halogen lamp (26.2%), while only 6.9% of them seem to prefer plasma lights [51-53].

Enamel Preparation

Primers

One of the main factors affecting the bond strength between the brackets and the enamel surface is the preparation of the tooth surface. Acid conditioning transforms the enamel surface from a low-energy hydrophobic surface to a high-energy hydrophilic surface, resulting in increased surface tension and wettability [54]. Orthophosphoric acid in concentrations ranging from 2% to 85% has been widely used to condition the enamel surface prior to orthodontic brackets bonding procedure [55-57]. The indicated application time is 30 sec. Other conditioning procedures have occasionally included the use of maleic acid [58,59]. Phosphoric acid and maleic acid etch the enamel surface in a similar way, although 10% maleic acid seems to remove significantly less enamel than 35% phosphoric acid gel [60]. The reaction products of these acids, however, differ: the reaction product of maleic acid is calcium maleate, whereas for phosphoric acid, whose concentrations exceed 27%, the principal reaction product is monocalcium phosphate monohydrate. Both products are soluble and thoroughly removed when the tooth surface is washed prior to drying and application of the adhesive [61]. The reaction product of phosphoric acid in concentrations less than 27% is dicalcium phosphate dihydrate, which is less soluble and could therefore have an adverse effect on the bond strength. However, the bond strength produced by phosphoric acid conditioners in these low concentrations is within acceptable limits. It has been suggested that a clinically adequate bond strength value for an orthodontic bracket is in the range of 6 MPa to 8 MPa, and all phosphoric acid conditioners and 10% maleic acid conditioners are well within or exceed these limits (etching with 37% phosphoric acid provides a SBS of about 13 MPa) [62]. Phosphoric acid conditioners in concentrations of 2% have been shown to result in minimal loss of superficial enamel with a considerable reduction in the length of resin tags [63]. As regards to the clean-up procedure, it seems to be more difficult when enamel is conditioned with 37% phosphoric acid compared to a 2% conditioner. The resin remnants in the first case need to be removed by carbide burs, whereas in the second case are easily scraped off with a scaler [63].

The phosphoric acid etch-and-rinse technique requires rinsing and drying the tooth after application of the etching agents. This procedure is sometimes troublesome and there is always the risk of saliva or blood contamination during the etching process, resulting thus to the deterioration of the bond strength [64,65] or form the need to repeat the procedure. Moreover, phosphoric acid techniques are associated with enamel loss, a risk of enamel cracks after debonding, and decalcifications, resulting into the formation of white spot lesions around bonded orthodontic appliances. In conservative dentistry, self-etching primers are being used more frequently to replace the phosphoric acid etch and rinse technique. They function both as etching agent and a primer. The procedure that rinsing off the enamel surface after its application is not required, results into the reduction of the number of clinical steps and minimizes the clinical operation time (approximately reduction of about 8 min). The shear bond strength they provide is slightly lower than that of phosphoric acid etching technique [66], but similar to that provided by RMGICs. Additionally, it has been shown that self-etch primers provide a clinically acceptable for orthodontic bonding bond strength of 12 MPa to 20 MPa (25% reduction in their mean bond strength), even when the enamel surface is contaminated with saliva [67], and they appear to have a lower decalcifying ability [68]. Since the purpose is not to obtain the highest possible bond strength, but adequate bond strength for orthodontic treatment purposes and conditions for the safe debonding, the self-etch primers seem to perform well. It has to be noted, though, that not all self-etching primers perform equally, since their concentrations in phosphoric acid differ.

In order to reduce even more the decalcifying ability of self-etch primers, experimental one-step or two-step bonding systems which incorporate antibacterial substances have been introduced into the market. The bond strength of one- and two-step self-etching adhesives has been reported comparable with conventional adhesive systems [69,70] and acceptable for orthodontic bracket bonding, since they provide a bond strength of approximately 9.50 MPa [71,72]. These products contain MDPB (12-methacryloyloxydodecyl-pyridinium bromide), an antibacterial monomer, which copolymerizes with other monomers after curing and the antibacterial agent is bonded to the polymer network, acting as contact inhibitor against the bacteria that attach to the surface [73]. Studies have confirmed the antibacterial ability of MDBP-containing primers and validated their usefulness [74]. Their antibacterial effect in combination with their simplified application procedures makes them a good choice for orthodontic bonding.

Under the same philosophy, newer self-adhesive cements have the potential to further simplify the bonding process, by reducing the process of bonding orthodontic brackets to a one-step procedure, since they theoretically do not require an etching or bonding step. Self-adhesive cements become the material of choice in many dental procedures. As regards the orthodontics, there are limited data evaluating these cements. The existing in vitro studies agree that the shear bond strength they provide is significantly lower than that of the traditional three- or two-step adhesive systems [75], but they present contradictory results as far as their clinical acceptance is regarded. Some studies show that the bond strength provided by self-adhesive cements is within the clinical acceptable limits (8 MPa), while others report shear bond strength below these limits (5 MPa to 6 MPa) [76]. The manufacturers should consider changes in the consistency and composition of self-adhesive cements for them to be potentially useful for successful bonding orthodontic brackets to enamel.

Supplementary techniques

A number of techniques used on bracket surfaces have been reported to increase bond strength between brackets and enamel. Micromechanical bonding systems, such as sandblasting with aluminum oxide particles remove the unfavorable oxides from the tooth surfaces, create a very fine roughness, increase the surface area, thereby enhancing mechanical and chemical bonding [77].

Advances in silane coupling agents contribute to high bond strengths by promoting a chemical bond between composite resins, ceramics and metals [78,79]. The application of a silane agent to base metal and silica-based ceramic surfaces after sandblasting with aluminum oxide particles produces higher bond strengths [79,80] compared to no treated surfaces.

The air abrasion technique based on tribochemical silica coating provides ultrafine mechanical retention and is also used as a silane coupling agent. The effect of tribochemical silica-coating system on bond strength can be explained by two mechanisms: a) the creation of a topographic pattern allowing for micromechanical bonding among the bracket, the resin luting agent and the enamel, and b) the chemical bond formed between the silica-coated metal and ceramic surface and resin material [81]. It has been reported that the airborne particles can penetrate up to 15 μm into the ceramic and metal substrates [82].

Shear bond strength seems to be significantly increased after sandblasting and/or after silanating. Newman et al. [79] reported that the bond strength of metal brackets after sandblasting was 10.9 MPa, after sandblasting and silanating 11.9 MPa, with Rocatec System 10.8 MPa and with Silicoater Classical 13.2 MPa, when the control group with no preparation provided a shear bond strength of 9.0 MPa. Atsu et al. [80] reported even higher shear bond values: 14.2 MPa when stainless steel orthodontic brackets were bonded after treatment with silica coating and silanization in comparison to 11.9 MPa of the control group with no treatment. Sandblasting with larger size abrasive particles (90 μm) shows significantly higher SBS values compared to that of smaller size abrasive particles (50 μm). Air abrasion without acid etching results in significantly lower bond strength and should not be advocated for clinical use [83-85].

Another way to prepare the enamel surface is by laser ablation. It seems that laser ablation provides similar SBS values as acid etching [86], whereas their combination provides no clinically significant further SBS values. Er: YAG laser, CO_2 laser and Ti: Sapphire laser are some of those that have been tested in comparison to conventional acid etching technique. Er: YAG laser results in better SBS values when the enamel surface is pretreated with quantum-square pulse mode [87], preparation with CO_2 laser provides lower SBS values than that of primary preparation with acid etching [88], whereas enamel preparation with Ti: Sapphire laser provides higher SBS values than both conventional acid etching technique and Er: YAG laser pretreatment [89].

Resin infiltration technique

The resin infiltration technique is basically applied on tooth surfaces in order to prevent the evolution of white spot lesions or to aesthetically improve them. Clinical follow-up studies have proved this concept to be more effective in stopping the progression of a carious lesion within 1.5 year of observation, in comparison to fluoridation measures [90]. Preconditioning with the caries infiltrant system seems to increase the shear bond strength of most orthodontic resins to sound and demineralized enamel. At the same time, the risk of enamel fractures while debonding is reduced and the amount of residual resin remains unchanged [91].

Cytotoxicity

Although the development of orthodontic resins is satisfying, their biocompatibility is still an issue. Polymerization process of dental resin based materials is usually incomplete under clinical conditions, even when mixed according to manufacturers' instructions. Leaching from resin composites may occur either during the setting period of the resin (related to the degree of conversion) or later when the resin is degraded [92]. Substances released from orthodontic composites may cause a reaction (inflamation or necrosis) in adjacent tissues, such as the oral mucosa and gingiva, or the aveolar bone. There are several ways that materials may influence the health of soft tissues: by delivering water soluble components into the saliva and the oral cavity or by interacting directly with adjacent tissues [93]. The resin matrix of the orthodontic composites consists of mainly two monomers (bis-GMA and TEGDMA), while other co-monomers (HEMA, EGDMA, DEGMA) and components, such as photo-initiators, inhibitors, ultraviolet absorbers, photo-stabilizers and pigments, co-exist. Both of bis-GMA and TEGMA have been implicated in a variety of cytotoxic responses observed in tissues. TEGDMA causes large deletions of DNA sequences, leading to chromosomal aberrations [94], whereas bis-GMA concentrations of 5 μmol/L produce a depression of DNA synthesis. Swallowed HEMA/TEGDMA gets almost completely absorbed by the organism. Additionally, resin adhesives around the bracket bases are under the influence of atmospheric oxygen, which compromises its polymerization reaction, leading to the increase of non polymerized monomers, resulting into more cytotoxic reactions [95]. Single-cure systems exhibit comparatively less cytotoxicity and higher degree of conversion, proving superior to dual-cure systems [96].

Clinical Recommendations

1. The light-cure tip should be kept as close to the adhesive resin as possible.
2. Irradiate around the bracket edges instead of irradiating through the bracket.
3. Excess removal is usually done after 2 sec to 5 sec of light cure and final curing is done after that.
4. Patients should rinse their mouths during the first hour after bracket bonding, for it might prevent their exposure to the potential hazard of leaching monomers [97].

Bonding to Different Substrates

Amalgam

In adult orthodontic patients, and occasionally in adolescents as well, amalgam restorations exist on the buccal surfaces of posterior teeth. In such cases, successful bonding of orthodontic attachments to amalgam surfaces is pretty challenging. This clinical problem led to the investigation of several procedures in order to improve the SBS in such cases. These procedures include surface treatment and the use of intermediate resins and adhesives which chemically bond to metals.

Surface treatment procedures include roughening the amalgam surface with a diamond bur, sandblasting [98-100], Ga-Sn liquid application [101], and chemical corrosion [102]. Sandblasting is the most common method used for surface preparation, since it creates scratch-like irregularities that increase bond strength. Air abrasion also increases the surface area of Co-Cr and Ni-Cr alloys leading to improved adhesion to resins containing 4-META [103]. In addition to mechanical retention, bonding to metal has the advantage of chemical adhesion. Therefore, adhesives chemically bonded to amalgam, such as 10-methacryloyloxydecyl dihydrogen phosphate bis-GMA resins or 4-META, which forms hydrogen bonds with the oxygen and hydroxyl groups in the metal oxide layer, are recommended [104]. The mean SBS values of stainless steel orthodontic brackets bonded to amalgam surfaces are significantly lower than those of brackets bonded to etched enamel, yet clinically acceptable [105]. Bond failures occur at the amalgam-adhesive interface regardless of the adhesive system and without any damage to the amalgam restoration.

Porcelain/ceramic restorations

Apart from amalgam restorations, many adult patients seeking orthodontic therapy have porcelain/ceramic restorations as well. When bonding to porcelain adequate bond strength is desired, with easy removal to avoid damage of the restored teeth. Several techniques have been used to bond brackets to porcelain surfaces and they differ in surface preparation and bonding agents applied. The adhesives used to bond brackets to ceramics (composite resins, RMGICs) seem to provide similar SBS values [106]. Surface preparation includes the application of different acids (orthophosphoric acid or hydrofluoric acid), treatment by different laser techniques, roughening by diamond burs, sandblasting and silanization. The use of hydrofluoric acid greatly increases the bond strength. This is due to the acid's ability to react with the silica phase, creating micromechanical retention through microchannels. Over time, the glassy matrix partially dissolves and increases the formation of such retentive channels. Longer etching time increases the bond strength as it allows the acid to react with the ceramic matrix even further. Considering the harmful effects of etching with HFA, mechanical roughening with sandblasting or mby diamond burs is recommended. In any case, the bond strength of brackets bonded to porcelain is further improved by the application of silane, which has the ability to form chemical bonds with inorganic and organic surfaces [107,108]. Yet, not every brand provides the same SBS values [108]. Conventional technique of HFA etching and silanization, sandblasting and silanization, orthophopsphoric acid etching and silanization, and HFA etching alone show higher SBS values than laser etching in combination with silane application, whereas orthophosphoric acid etching alone and sandblasting alone show lower SBS values than laser application alone [109,110]. Nd: YAG laser seems to be an acceptable substitute for HFA, however the Er: YAG laser is not acceptable option [111]. The best protocol for bonding to porcelain described is acid etching with 9.6% HFA, rinsing for 30 sec, air-drying and silanization [112]. However, there are differences between various ceramic surfaces and brands, such as dissimilar particle size and crystaline structure, leading to higher or lower bond strengths. Higher SBS values are presented by Empress II and Finesse, ceramo-metal and in-ceram have comparable SBS, while IPS Empress shows the weakest bond strength [112-116].

Bleached teeth

Various bleaching agents and methods exist to whiten discolored teeth at the office or at home. The results of the studies studying the affect of bleaching to the bond strength of orthodontic brackets are controversial: there are studies reporting no adverse effect on the SBS of orthodontic brackets [117], and there are others reporting considerable reduction of SBS values subsequent to bleaching [118]. The reduced SBS values may be attributed to alterations in the microstructure of bleached enamel surfaces after acid etching, including reduced micro hardness, calcium loss, over etching and loss of enamel prisms [119], or other underlying mechanisms, such as the release of oxygen radicals on the enamel surface by residual components of bleaching agents [120].

In order to avoid bonding failure on bleached teeth, several methods have been proposed. These methods include the avoidance the bleaching process until the orthodontic treatment is completed, the delay of bracket bonding up to 4 weeks after bleaching, pumicing the bleached teeth and the application of antioxidant agents, such as 10% sodium ascorbate or 10% α-tocopherol, prior to bracket bonding, in order to neutralize the effect of released oxygen radicals from residual components [120]. Antioxidant agents seem to increase the SBS of orthodontic brackets bonded to bleached teeth, even when applied 3 h after the bleaching procedure. The application time needed in order the gel to be efficient is at least 60 min therefore its application by the patient might reduce chair time [121].

Fluorosis

Although the enamel crystals in fluorosed teeth may be separated by larger inter-rod spaces, no other significant difference in the enamel crystals is observed compared to those of non-fluorosed teeth [122]. However, there are several studies reporting that fluorosis has a negative influence on the SBS of orthodontic brackets [123]. Enamel fluorosis significantly decreases the SBS of orthodontic brackets when standard etching protocol is used, yet satisfactory SBS is obtained when self-etching primer is used for bonding brackets to flurosed teeth [124]. Further improvement of the SBS values shall occur when the fluorosed enamel surface gets air abraised prior to etching procedure [125], or by the application of the resin infiltration technique [126].

Debonding

When a bonded bracket is removed failure can occur at one of the three interfaces: between the adhesive and enamel surface, within the bonding material itself, or between the adhesive cement and the bracket. The interface between the adhesive cement and the bracket is the most usual site of failure [127] and the remaining adhesive must be removed. The use of adhesive-removal pliers may cause pain, while physical changes to the enamel can occur as well, ranging from surface roughening to microscopic fractures. A wide variety of instruments and procedures has been introduced as a result of the search of an efficient and safe method of adhesive removal after debonding. These include manual removal with the use of scaler or a band removing plier, various shapes of tungsten-carbide burs with high or low speed hand pieces, specially designed burs which are less aggressive to the enamel, Sof-lex discs, special composite finishing systems with zirconia paste or slurry pumice, ultrasonic applications, while methods such as CO_2 laser application or powder abrasive systems are quite promising [128]. The color of the enamel can also be affected both by debonding and by the following cleaning procedures [129]. Changes in the color of the enamel may also result from the discoloration of the residual resin irreversibly penetrated the surface, despite the cleaning procedures. The average depth of penetration ranges between 8 µm and 15 µm, with maximum tag lengths ranging up to 50 µm. Removing all these residues would signify a considerable loss of sound tooth structure. Most desirable would be the availability of a bonding agent with both the least discoloration potential and the ability to remove its residue by a simple protocol. When the brackets are bonded with the etch-and-rinse or self-etching systems, cleaning the adhesives with Stain bluster burs is recommended, whereas for the RMGICs, tungsten carbide burs may provide less enamel discoloration in the long run. The combination of etch-and-rinse system and tungsten carbide burs is not recommended for clinical use, since it seems to cause the highest color change [130].

In general, the weaker chemical bonding between GICs/RMGICs and the enamel makes it easier for the clinicians to clean up the adhesive on the enamel surface after debonding in comparison to when brackets are bonded with composite resin.

Failures

Bonded brackets should ideally remain attached to the tooth surface throughout the whole treatment, whereas the bond strength of the bonding material should be sufficient to resist tensile, shear, torque and peel functional stresses [131]. Bond failure, however, is encountered frequently during treatment and may be influenced by the micro structure of the bracket base, etching time, the etching system, the bonding agent and the bonding technique used. In addition factors related to the operator, such as moisture control during bonding procedure, choice of bonding material, choice of brackets or instructions given to the patients, and patient, such as sex, age, malocclusion and dental hygiene, are likely to influence the failure rate of any bonding system. Most fixed appliance orthodontic treatments last about 18 months. The more limited the bond failure is during this period of time, the better for the clinical result. The acceptable levels of bond failure for in vivo use are 4% to 10%. According to the literature, composite resins have an average failure rate of about 6% (study results range between 4.7% and 8.3%) [132]. These failure rates are comparable to those of RMGICs, when applied in combination with prior etching. Their average failure rate is 7% (with studies reporting failure rates from 5% to 8.9%). Higher failure rates are expected when the enamel is dried prior to bonding with RMGICs [133]. Both composite resins and RMGICs have significantly lower failure rates than GICs, which seem to have a failure rate ranging from 12% to 50%. The disadvantage of extra bracket failures appears to outweigh any potential advantages when considering GICs for bonding of orthodontic brackets.

Even though bonds can fail on any tooth at any time, generalizations have been made, such as that most failures occur at the bonding visit or some time before the first post bonding visit, incisors and canines have fewer failures than premolars, maxillary canine bonds are more successful than mandibular canine bonds or that clinically anterior bonds separate more at the bracket/ resin interface, whereas posterior teeth are more likely to demonstrate an enamel/resin break [134]. In any case, bond failure is of particular concern clinically and its cause should be ascertained and addressed accordingly whenever possible.

Rebonding

Bracket rebonding is a frequent and undesirable problem during orthodontic treatment, while, sometimes, rebonding is intentional, in order for the bracket to be located in a more appropriate position.

As regards to the SBS values of rebonded brackets the results in the existing literature are contradictory. There are studies supporting limited SBS values, and the fact that the new bond failure rate increases up to 10% to 25%, as a result of the alteration in the enamel microstructure, due to the remaining residual adhesives on the enamel surface, even after the enamel clean-up procedure. Other studies claim that when the conditioner is reapplied on the enamel surface dissolving the enamel prisms which support the remaining resin tags, these resin tags acquire a mushroom-like shape, allowing the resin to extend under them, thus increasing the micromechanical retention and the bond strength. Different enamel treatment methods have been proposed prior to rebonding, such as acid etching alone (self-etch primers seem to provide not only comparable, but even higher bond strength than that of the conventional phosphoric acid after the first debonding) [135] or in combination with surface roughening by sandblasting (although it seems not to have any major benefit in terms of increasing the SBS compared with acid etching alone) [136] silane application (especially when rebonding ceramic brackets) and the use of adhesion boosters. At last, there are also studies supporting that omitting the acid etching step can achieve adequate SBS values, since the surface of the enamel after the cleanup procedure is more active and available for chemical bonding. Cleaning the enamel surface with low-speed TCB, high-speed TCB or Solf-Lex discs, the shear rebond strengths are even higher than the initial bond strengths.

When rebonding, the time it takes to clean, prepare and bond a new bracket can be disruptive in a busy practice and might also lengthen the overall treatment time. If debonding is carried out in a way that the bracket is removed without any damage, it can be reused following different forms of processing. Whether a bracket can be recycled or not, depends on both the adhesive and the removal device used. For example, GICs and RMGICs are easier to remove than composite resins, and regardless of the adhesive used, brackets removed with a lift off de-bracketing instrument or air pressure pulse device seem to be always reusable, whereas brackets removed with removal pliers or side cutters not. The SRS of recycled brackets is affected by several factors including microscopic damage to the bracket base, base design, and amount of remaining adhesive on the bracket base, as well as the method used for the adhesive removal. Treatment of recycled bracket surface with Er: YAG seems to provide SRS values comparable to those of sandblasted brackets, both significantly higher than treatment with CO_2 laser, causing minimum damage to the bracket base.

References

1. Barry GR. A clinical investigation of the effects of pumice prophylaxis on band and bond failure. Br J Orthod 1995;22(3):245-8.
2. Bearn DR, Aird JC, McCabe JF. Ex vivo bond strength of adhesive precoated metallic and ceramic brackets. Br J Orthod 1995;22(3):233-6.
3. Bin Abdullah MS, Rock WP. The effect of etch time and debond interval upon the shear bond strength of metallic orthodontic brackets. Br J Orthod.1996;23(2):121-4.
4. Banerjee A, Paolinelis G, Socker M, Watson TF, McDonald F. An in-vitro investigation of the effectiveness of bioactive glass air-abrasion in the selective removal of orthodontic resin adhesive. Eur J Oral Sci. 2008;116(5):488-92.
5. Buonocore MG. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. J Dent Res 1955;34(6):849-53.
6. Newman GV, Snyder WH, Wilson CW. Acrylic adhesives for bonding

attachments to tooth surfaces. Angle Orthod. 1968;38(1):12-18.

7. Newman GF. Adhesion and orthodontic plastic attachments. Am J Orthod. 1969;56(6):573-88.
8. Weisser JI. A successful method for bonding stainless steel brackets and auxiliaries. J Clin Orthod. 1973;7(10):637-45.
9. Silverman E, Cohen M, Gianelly AA, Dietz VS. A universal direct bonding system for both metal and plastic brackets. Am J Orthod. 1972;62(3):236-44.
10. Trimpeneers LM, Verbeeck RMH, Dermaut LR, Moors MG. Comparative shear bond strength of some orthodontic bonding resins to enamel. Eur J Orthod. 1996;18(1):89-95.
11. Graf I, Jacobi BE. Bond strength of various fluoride - releasing orthodontic bonding systems. Experimental study. J Orofac Orthop. 2000;61(3):191-8.
12. Beech DR, Jalaly T. Bonding of polymers to enamel: influence of deposits formed during etching, etching time and period water immersion. J Dent Res. 1980;59(7):1156-61.
13. Bishara SE, Von Wald L, Laffon JF, Jacobsen JR. Effect of altering the type of enamel conditioner on the shear bond strength of a resin-reinforced glass ionomer adhesive. Am J Orthod Dentofacial Orthop. 2000;118(3):288-94.
14. Erickson RL, Glasspoole EA. Adhesion a la estructura dentaria: comparacion de los ionomeros de vidrio y los composites. J Esthet Dent. 1995;5:1-26.
15. Joseph VP, Rossouw E. The shear bond strengths of stainless steel and ceramic brackets used with chemically and light-activated composite resins. Am J Orthod Dentofacial Orthod. 1990;97(2):121-5.
16. Caughman WF, Rueggeberg FA. Shedding new light on composite polymerization. Oper Dent. 2002;27(6):636-8.
17. Tavas MA, Watts DC. Bonding of orthodontic brackets by transillumination of a light activated composite: an in vitro study. Br J Orthod. 1979;6(4):207-8.
18. Eller B, Plenk H. Grundlagen and derzeitiger Stand der Schmelzatzungs und Bracketklebetechniken. Zeitschrift fur Stomatologie. 1994;8:385-97.
19. Boaro LC, Gonçalves F, Guimarães TC, Ferracane JL, Versluis A, Braga RR. Polymerization stress, shrinkage and elastic modulus of current low-shrinkage restorative composites. Dent Mater. 2010;26(12):1144-50.
20. Tabrizi S, Salemis E, Usumez S. Flowable composites for bonding orthodontic retainers. Angle Orthod. 2010;80(1):195-200.
21. Ryou DB, Park HS, Kim KH, Kwon TY. Use of flowable composites for orthodontic bracket bonding. Angle Orthod. 2008;78(6):1105-9.
22. D'Attilio M, Traini T, Di Iorio D, Varvara G, Festa F, Tecco S. Shear bond strength, bond failure, and scanning electron microscopy analysis of a new flowable composite for orthodontic use. Angle Orthod. 2005;75(3):410-5.
23. Wilson AD, Kent BE. A new translucent cement for dentistry. British Dental Journal 1972;132:(4)133-35.
24. Frankenberger R, Lopes M, Perdigão J, Ambrose WW, Rosa BT. The use of flowable composites as filled adhesives. Dent Mater. 2002;18(3):227-38.
25. Pick B, Rosa V, Azeredo TR, Cruz Filho EA, Miranda WG. Are flowable resin based composites a reliable material for metal orthodontic bracket bonding? J Contemp Dent Pract. 2010;11(4):E017-24.
26. Ferracane JL. Developing a more complete understanding of stresses produced in dental composites during polymerization. Dent Mater. 2005;21(1):36-42.
27. De Munck J, Van Landuyt KL, Coutinho E, Poitevin A, Peumans M, Lambrechts P, et al. Fatigue resistance of dentin/composite interfaces with an additional intermediate elastic layer. Eur J Oral Sci. 2005;113(1):77-82.
28. Nomoto R. Effect of light wavelength on polymerization of light-cured resins. Dent Mater J 1997;16(1):60-73.
29. Cook WD. Spectral distributions of dental photopolymerization sources. J Dent Res 1982;61:1436-8.
30. Jandt KD, Mills RW, Blackwell GB, Ashworth SH. Depth of cure and compressive strength of dental composites cured with blue light emitting diodes (LEDs). Dent Mater 2000;16(1):41-7.
31. Stahl F, Ashworth SH, Jandt KD, Mills RW. Light-emitting diode (LED) polymerization of dental composites: flexural properties and polymerization potential. Biomaterials 2000;21(13):79-85.
32. Althoff O, Hartung. Advances in light curing. Am J Dent. 2000;13:77-81.
33. Fujibayashi K, Ishimaru K, Takahashi N, Kohno A. Newly developed curing unit using blue light emitting diodes. Dent Jap. 1998;34:49-53.
34. Rueggeberg FA, Caughman WF, Curtis JW. Effect of light intensity and exposure duration on cure of resin composite. Oper Dent 1994;19(1):26-32.
35. Swartz ML, Philips RW, Rhodes B. Visible light-activated resins-depth of cure. JADA 1983;106(5):634-37.
36. Bishara SE, VonWald L, Zamtua J. Effects of different types of light guides on shear bond strength. Am J Orthod Dentofacial Orthop 1998;114(4):447-51.
37. Evans LJ, Peters C, Flickinger C, Taloumis L, Dunn W. Comparisons of shear bond strengths of orthodontic brackets using various light sources, light guides, and cure times. Am J Orthod Dentofacial Orthop. 2002;121(5):510-15.
38. Curtis JW Jr, Rueggeberg FA, Lee AJ. Curing efficiency of the Turbo Tip. Gen Dent. 1995;43(5):428-33.
39. Oesterle LJ, Newman SM, Shellhart WC. Rapid curing of bonding composite with a xenon plasma arc light. Am J Orthod Dentofacial Orthop. 2001;119(6):610-16.
40. Peutzfeldt A, Sahafi A, Asmussen E. Characterization of resin composites polymerizes with plasma arc units. Dent Mater. 2000;16(5):330-6.
41. Klocke A, Korbmacher HM, Huck LG, Kahl- Nieke B. Plasma arc curing lights for orthodontic bonding. Am J Orthod Dentofacial Orthop. 2002;122(6):643-8.
42. Clinical Research Associates. Resin curing lights. Newsletter. 2000;24:1-4.
43. Mills RW. Blue light emitting diodes – another method of light curing? Br Dent J. 1995;178(5):169.
44. Mills RW, Jandt KD, Ashworth SH. Dental composite depth of cure with halogen and blue light emitting diode technology. Br Dent J. 1999;186(8):388-91.
45. Koupis NS, Eliades T, Athanasiou AE. Clinical evaluation of bracket bonding using two different polymerization sources.Angle Orthod. 2008;78(5):922-5.
46. Fleming PS, Eliades T, Katsaros C, Pandis N. Curing lights for orthodontic bonding: a systematic review and meta-analysis. Am J Orthod Dentofacial Orthop. 2013;143:S92-103.
47. Retamoso LB, Onofre NM, Hann L, Marchioro EM. Effect of light-curing units in shear bond strength of metallic brackets: an in vitro study. J Appl Oral Sci. 2010;18(1):68-74.
48. Bishara SE, Ajlouni R, Oonsombat C. Evaluation of a new curing light on the shear bond strength of orthodontic brackets. Angle Orthod. 2003;73(4):431-5.
49. Oyama N, Komori A, Nakahara R. Evaluation of light curing units used for polymerization of orthodontic bonding agents. Angle Orthod. 2004;74(6):810-5.

50. Cacciafesta V, Sfondrini MF, Scribante A, Boehme A, Jost-Brinkmann PG. Effect of light-tip distance on the shear bond strengths of composite resin. Angle Orthod. 2005;75(3):386-91.

51. Kao EC, Rezvan E, Eliades T, Johnson WM. Debond sheer force of light cured glass ionomer cements [Abstract]. J Dent Res. 1994;73:413.

52. Retief DH. The use of 50 per cent phosphoric acid as an etching agent in orthodontics: a rational approach. Am J Orthod. 1975;68(2):165-78.

53. Gottlieb EW, Retief DH, Jamison HC. An optimal concentration of phosphoric acid as an etching agent. Part I: Tensile bond strength studies. J Prosthet Dent. 1982;48(1):48-51.

54. Zidan O, Hill G. Phosphoric acid concentration: enamel surface loss and bonding strength. J Prosthet Dent. 1986;55(3):388-92.

55. MacColl G. The relationship between bond strength and base surface area using conventional and micro-etched bases (thesis). Toronto: Faculty of Dentistry, Department of Orthodontics. 1995.

56. Swift EJ Jr, Cloe BC. Shear bond strengths of new enamel etchants. Am J Dent. 1993;6(3):162-4.

57. Hermsen RJ, Vrijhoef MM. Loss of enamel due to etching with phosphoric or maleic acid. Dent Mater. 1993;9(5):332-6.

58. Weast RC. Handbook of chemistry and physics.. Cleveland: CRC Press, B-78. 1974.

59. Fowler CS, Swartz ML, Moore BK, Rhodes BF. Influence of selected variables on adhesion testing. Dent Mater. 1992;8(4):265-9.

60. Urabe H, Rossouw PE, Titley KC, Yamin C. Combinations of etchants, composite resins, and bracket systems: an important choice in orthodontic bonding procedures. Angle Orthod. 1999;69(3):267-75.

61. Yamamoto T. The effect of contamination on the adhesion of composite resin to etched enamel surface. Jpn J Conserv Dent. 1981;24:93-114.

62. Xie J, Powers JM, McGuckin RS. In vitro bond strength of two adhesives to enamel and dentin under normal and contaminated conditions. Dent Mater. 1993;9(5):295-9.

63. Yamada R, Hayakawa T, Kasai K. Effect of using self-etching primer for bonding orthodontic brackets. Angle Orthod. 2002;72(6):558-64.

64. Bishara SE, Oonsombat C, Ajlouni R, Denehy G. The effect of saliva contamination on shear bond strength of orthodontic brackets when using a self-etch primer. Angle Orthod. 2002;72(6):554-7.

65. Pashley DH, Tay FR. Aggressiveness of contemporary self-etching adhesives. Part II: etching effects on unground enamel. Dent Mater. 2001;17(5):430-44.

66. Cehreli ZC, Kecik D, Kocadereli I. Effect of self-etching primer and adhesive formulations on the shear bond strength of orthodontic brackets. Am J Orthod Dentofacial Orthop. 2005;127(5):573-9.

67. Bishara SE, Oonsombat C, Ajlouni R, Laffoon JF. Comparison of the shear bond strength of 2 self-etch primer/adhesive systems. Am J Orthod Dentofacial Orthop. 2004;125(3):348-50.

68. Eminkahyagil N, Korkmaz Y, Gokalp S, Baseren M. Shear bond strength of orthodontic brackets with newly developed antibacterial self-etch adhesive. Angle Orthod. 2005;75(5):843-8.

69. Imazato S. Antibacterial properties of resin composites and dentin bonding systems. Dent Mater. 2003;19(6):449-57.

70. Kaneko T, Imazato S, Ebi N, Kuramoto A, Noiri Y, Ebisu S. In vivo antibacterial effect of dentin primer incorporating MDPB. J Dent Res. 2001;80:659.

71. Bishara SE, Ostby AW, Ajlouni R, Laffoon JF, Warren JJ. Early shear bond strength of a one-step self-adhesive on orthodontic brackets. Angle Orthod. 2006;76(4):689-93.

72. Vicente A, Bravo LA, Romero M, Ortiz AJ, Canteras M. A comparison of the shear bond strength of resin cement and two orthodontic resin adhesive systems. Angle Orthod. 2004;75(1):109-13.

73. Peutzfeldt A, Asmussen E. Silicoating: evaluation of a new method of bonding composite resin to metal.Scand J Dent Res. 1988;96(2):171-6.

74. Plueddemann PE. Nature of adhesion through silane coupling agents. 1982:111.

75. Blatz MB, Sadan A, Kern M. Resin-ceramic bonding: a review of the literature. J Prosthet Dent. 2003;89(3):268-74.

76. Thurmond JW, Barkmeier WW, Wilwerding TM. Effect of porcelain surface treatments on bond strengths of composite resin bonded to porcelain. J Prosthet Dent. 1994;72(4):355-9.

77. Wegner SM, Kern M. Long-term resin bond strength to zirconia ceramic.J Adhes Dent. 2000;2(2):139-47.

78. Sun R, Suansuwan N, Kilpatrick N, Swain M. Characterisation of tribochemically assisted bonding of composite resin to porcelain and metal. J Dent. 2000;28(6):441-5.

79. Newman GV, Newman RA, Sun BI, Ha JL, Ozsoylu SA. Sandblasting, silanating, and coatings: their effects on bond strength of metal brackets: an in vitro study. J N J Dent Assoc. 1995;66(1):15-7.

80. Atsü S, Çatalbaş B, Gelgör İE. Effects of silica coating and silane surface conditioning on the bond strength of rebonded metal and ceramic brackets. J Appl Oral Sci. 2011;19(3):233-9.

81. Abu Alhaija ES, Al-Wahadni AM. Evaluation of shear bond strength with different enamel pre-treatments. Eur J Orthod. 2004;26(2):179-84.

82. Lee BS, Hsieh TT, Lee YL, Lan WH, Hsu YJ, Wen PH, et al. Bond strengths of orthodontic bracket after acid-etched, Er:YAG laser-irradiated and combined treatment on enamel surface. Angle Orthod. 2003;73(5):565-70.

83. Sağır S, Usumez A, Ademci E, Usumez S. Effect of enamel laser irradiation at different pulse settings on shear bond strength of orthodontic brackets. Angle Orthod. 2013;83(6):973-80.

84. Oshagh M, Pakshir HR, Najafi HZ, Naseri MM, Nasrabadi NI, Torkan S. Comparison of the shear bond strength of orthodontic brackets in bonding and rebonding: preparation with laser versus conventional acid etch technique. Photomed Laser Surg. 2013;31(8):360-4.

85. Olsen ME, Bishara SE, Damon P, Jakobsen JR. Evaluation of Scotchbond Multipurpose and maleic acid as alternative methods of bonding orthodontic brackets. Am J Orthod Dentofacial Orthop. 1997;111(5):498-501.

86. Paris S, Meyer-Lueckel H. Infiltrants inhibit progression of natural caries lesions in vitro. J Dent Res. 2010;89(11):1276-80.

87. Naidu E, Stawarczyk B, Tawakoli PN, Attin R, Attin T, Wiegand A. Shear bond strength of orthodontic resins after caries infiltrant preconditioning. Angle Orthod. 2013;83(2):306-12.

88. Hanks CT, Strawn SE, Wataha JC, Craig RG. Cytotoxic effects of resin components on cultured mammalian fibroblasts. J Dent Res. 1991;70(11):1450-5.

89. Huang TH, Tsai CY, Chen SL, Kao CT. An evaluation of the cytotoxic effects of orthodontic bonding adhesives upon a primary human oral gingival fibroblast culture and a permanent, human oral cancer-cell line. J Biomed Mater Res. 2002;63(6):814-21.

90. Schweikl H, Schmalz G, Spruss T. The induction of micronuclei in vitro by unpolymerized resin monomers. J Dent Res. 2001;80(7):1615-20.

91. Yap AU, Lee HK, Sabapathy R. Release of methacrylic acid from dental composites. Dent Mater. 2000;16(3):172-9.

92. Jagdish N, Padmanabhan S, Chitharanjan AB, Revathi J, Palani G,

Sambasivam M, et al. Cytotoxicity and degree of conversion of orthodontic adhesives. Angle Orthod. 2009;79(6):1133-8.

93. Attin R, Stawarczyk B, Keçik D, Knösel M, Wiechmann D, Attin T. Shear bond strength of brackets to demineralize enamel after different pretreatment methods. Angle Orthod. 2012;82(1):56-61.

94. Zachrisson BU, Büyükyilmaz T, Zachrisson YO. Improving orthodontic bonding to silver amalgam. Angle Orthod. 1995;65(1):35-42.

95. Büyükyilmaz T, Zachrisson BU. Improved orthodontic bonding to silver amalgam. Part 2. Lathe-cut, admixed, and spherical amalgams with different intermediate resins. Angle Orthod. 1998;68(4):337-44.

96. Skilton JW1, Tyas MJ, Woods MG. Effects of surface treatment on orthodontic bonding to amalgam.Aust Orthod J. 2006 May;22(1):59-66.

97. Gross MW, Foley TF, Mamandras AH. Direct bonding to Adlloy-treated amalgam. Am J Orthod Dentofacial Orthop. 1997;112(3):252-8.

98. Sperber RL, Watson PA, Rossouw PE, Sectak of PA. Adhesion of bonded orthodontic attachments to dental amalgam: In vitro study.Am J Orthod Dentofacial Orthop. 1999;116(5):506-13.

99. Atta MO, Smith BG, Brown D. Bond strengths of three chemical adhesive cements adhered to a nickel-chromium alloy for direct bonded retainers. J Prosthet Dent. 1990;63(2):137-43.

100. Zachrisson BU, Buyukyilimaz T. Recent advances in bonding to gold, amalgam and porcelain. Journal of Clinical Orthodontics. 1993;27(12):661-675.

101. Germec D, Cakan U, Ozdemir FI, Arun T, Cakan M. Shear bond strength of brackets bonded to amalgam with different intermediate resins and adhesives. Eur J Orthod. 2009;31(2):207-12.

102. Rambhia S, Heshmati R, Dhuru V, Iacopino A. Shear bond strength of orthodontic brackets bonded to provisional crown materials utilizing two different adhesives. Angle Orthod. 2009;79(4):784-9.

103. Eslamian L, Ghassemi A, Amini F, Jafari A, Afrand M. Should silane coupling agents be used when bonding brackets to composite restorations? An in vitro study. Eur J Orthod. 2009;31(3):266-70.

104. Costa AR, Correr AB, Puppin-Rontani RM, Vedovello SA, Valdrighi HC, Correr-Sobrinho L, et al. Effect of bonding material, etching time and silane on the bond strength of metallic orthodontic brackets to ceramic. Braz Dent J. 2012;23(3):223-7.

105. An KM, Sohn DS. The effect of using laser for ceramic bracket bonding of porcelain surfaces. Korean J Orthod. 2008;38(4):275-282.

106. Akova T, Yoldas O, Toroglu MS, Uysal H. Porcelain surface treatment by laser for bracket-porcelain bonding. Am J Orthod Dentofacial Orthop. 2005;128(5):630-7.

107. Poosti M, Jahanbin A, Mahdavi P, Mehrnoush S. Porcelain conditioning with Nd:YAG and Er:YAG laser for bracket bonding in orthodontics. Lasers Med Sci. 2012;27(2):321-4.

108. Grewal Bach GK, Torrealba Y, Lagravère MO. Orthodontic bonding to porcelain: a systematic review. Angle Orthod. 2014;84(3):555-60.

109. Abu Alhaija ES, Al-Wahadni AM. Shear bond strength of orthodontic brackets bonded to different ceramic surfaces. Eur J Orthod. 2007;29(4):386-9.

110. Karan S, Büyükyilmaz T, Toroğlu MS. Orthodontic bonding to several ceramic surfaces: are there acceptable alternatives to conventional methods? Am J Orthod Dentofacial Orthop. 2007;132(2):144.e7-14.

111. Proffit WR. The third stage of comprehensive treatment: finishing. In: Contemporary orthodontics. 2013;582-605.

112. Saraç YŞ, Külünk T, Elekdağ-Türk S, Saraç D, Türk T. Effects of surface-conditioning methods on shear bond strength of brackets bonded to different all-ceramic materials. Eur J Orthod. 2011;33(6):667-72.

113. Türk T, Saraç D, Saraç YS, Elekdağ-Türk S. Effects of surface conditioning on bond strength of metal brackets to all-ceramic surfaces. Eur J Orthod. 2006;28(5):450-6.

114. Bishara SE, Oonsombat C, Soliman MM, Ajlouni R, Laffoon JF. The effect of tooth bleaching on the shear bond strength of orthodontic brackets.Am J Orthod Dentofacial Orthop. 2005;128(6):755-60.

115. Lai SC, Tay FR, Cheung GS, Mak YF, Carvalho RM, Wei SH, et al. Reversal of compromised bonding in bleached enamel. J Dent Res. 2002;81(7):477-81.

116. Türkkahraman H, Adanir N, Güngör AY. Bleaching and desensitizer application effects on shear bond strengths of orthodontic brackets. Angle Orthod. 2007;77(3):489-93.

117. Bulut H, Kaya AD, Turkun M. Tensile bond strength of brackets after antioxidant treatment on bleached teeth. Eur J Orthod. 2005;27(5):466-71.

118. Kaya AD, Türkün M, Arici M. Reversal of compromised bonding in bleached enamel using antioxidant gel. Oper Dent. 2008;33(4):441-7.

119. Fejerskov O, Manji F, Baelum V. The nature and mechanisms of dental fluorosis in man. J Dent Res. 1990;69:692-700.

120. Adanir N, Türkkahraman H, Yalçin Güngör A. Effects of adhesion promoters on the shear bond strengths of orthodontic brackets to fluorosed enamel. Eur J Orthod. 2009;31(3):276-80.

121. Isci D, Sahin Saglam AM, Alkis H, Elekdag-Turk S, Turk T. Effects of fluorosis on the shear bond strength of orthodontic brackets bonded with a self-etching primer. Eur J Orthod. 2011;33(2):161-6.

122. Suma S, Anita G, Chandra Shekar BR, Kallury A. The effect of air abrasion on the retention of metallic brackets bonded to fluorosed enamel surface. Indian J Dent Res. 2012;23(2):230-5.

123. Proffit WR . The third stage of comprehensive treatment: finishing. In: Contemporary orthodontics, 5th ed, Proffit WR, Fields HW, Sarver DM eds, Mosby Elsevier, St Louis. 2013;582-605.

124. Eminkahyagil N, Arman A, Cetinşahin A, Karabulut E. Effect of resin-removal methods on enamel and shear bond strength of rebonded brackets. Angle Orthod. 2006;76(2):314-21.

125. Eliades T, Kakaboura A, Eliades G, Bradley TG. Comparison of enamel colour changes associated with orthodontic bonding using two different adhesives. Eur J Orthod. 2001;23(1):85-90.

126. Boncuk Y, Cehreli ZC, Polat-Özsoy Ö. Effects of different orthodontic adhesives and resin removal techniques on enamel color alteration. Angle Orthod. 2014;84(4):634-41.

127. Hitmi L, Muller C, Mujajic M, Attal JP. An 18-month clinical study of bond failures with resin-modified glass ionomer cement in orthodontic practice. Am J Orthod Dentofacial Orthop. 2001;120(4):406-15.

128. Cacciafesta V, Bosch C, Melsen B. Clinical comparison between a resin-reinforced self-cured glass ionomer cement and a composite resin for direct bonding of orthodontic brackets. Part 2: Bonding on dry enamel and on enamel soaked with saliva. Clin Orthod Res. 1999;2(4):186-93.

129. Egan FR, Alexander SA, Cartwright GE. Bond strength of rebonded orthodontic brackets. Am J Orthod Dentofacial Orthop. 1996;109(1):64-70.

130. Montasser MA, Drummond JL, Evans CA. Rebonding of orthodontic brackets. Part I, a laboratory and clinical study. Angle Orthod. 2008;78(3):531-6.

131. Pakshir HR, Zarif Najafi H, Hajipour S. Effect of enamel surface treatment on the bond strength of metallic brackets in rebonding process. Eur J Orthod. 2012;34(6):773-7.

132. Falkensammer F, Jonke E, Bertl M, Freudenthaler J, Bantleon HP. Rebonding performance of different ceramic brackets conditioned with a

new silane coupling agent. Eur J Orthod. 2013;35(1):103-9.

133. Vijayakumar A, Venkateswaran S, Krishnaswamy NR. Effects of three adhesion boosters on the shear bond strength of new and rebonded brackets--an in vitro study. World J Orthod. 2010;11(2):123-8.

134. Zhang QF, Yao H, Li ZY, Jin L, Wang HM. Optimal enamel conditioning strategy for rebonding orthodontic brackets: a laboratory study. Int J Clin Exp Med. 2014 15;7(9):2705-2711.

135. Knösel M, Mattysek S, Jung K, Kubein-Meesenburg D, Sadat-Khonsari R, Ziebolz D. Suitability of orthodontic brackets for rebonding and reworking following removal by air pressure pulses and conventional debracketing techniques. Angle Orthod. 2010;80(4):461-7.

136. Yassaei S, Aghili H, KhanPayeh E, Goldani Moghadam M. Comparison of shear bond strength of rebonded brackets with four methods of adhesive removal. Lasers Med Sci. 2014;29(5):1563-8.