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1. Introduction

A reliable bond to dental hard tissues and materials has always been one of the most significant contributions for restorative dentistry (Leinfelder, 2001). A durable and stable bond between resins and dental hard tissues and restorative materials which has to integrate all parts of the system into one coherent structure is fundamental for the long-term retention and clinical success of the restorations. However, micromechanical attachment is one of the key mechanisms for a reliable adhesion to dental hard tissues and restorative materials (Matinlinna & Vallitu, 2007; Van Noort, 2002b; Fabienelli, et al., 2010). Advances in adhesive dentistry have resulted in the recent introduction of modern surface conditioning methods in order to achieve high bond strengths through increased surface roughness of both dental hard tissues and the restorative materials (Matinlinna & Vallitu, 2007; Van Noort, 2002b).

The use lasers in dentistry has evolved since their development in 1962. Researches have been carried out on effects of lasers on dental hard tissues and materials and applications of different wavelengths as they become available (Roberts-Harry, 1992; Convissar & Goldstein, 2001; White, et al., 1993; Frentzen, et al., 1992; Arima & Matsumoto, 1993; Wilder-Smith, et al., 1997; Cernavin, 1995; Keller & Hilbst, 1989; Burkes, et al., 1992; Wigdor, et al., 1993; Visuri, et al., 1996b). According to current literature there is no optimum wavelength for all dental applications. Each wavelength has distinct treatment advantages and offers various treatment options. Understanding the differences between laser wavelengths will help to choose the adequate wavelength for each application in the dental office (Kutsch, 1993).

Laser light has properties such as being coherent, monochromatic and collimated. Laser light travels in specific wavelengths in a predictable pattern (coherent) and parallel (collimated) and it has one color (monochromatic). Lasers and target tissues interact in four ways. When a laser light hits the target it can be reflected, absorbed, scattered throughout the target or transmitted into the target (Kutsch, 1993). During laser application light energy is converted into heat and energy absorption on the target surface causes the vaporization. This process is called ablation or photoablation by vaporization (Cardoso, et al., 2008; Esteves-Oliveira, et al., 2007; Tachibana, et al., 2008; Lee, et al., 2007). Among currently available lasers, the erbium:yttrium-
aluminum-garnet (Er:YAG) and Erbium, Chromium: Yttrium-Scandium-Gallium-Garnet (Er, Cr:YSGG) lasers have been proposed for different dental applications, including carious dentin removal, cavity preparation, surface conditioning, and as a surface treatment method for indirect restorations (Trajtenberg, et al., 2004; Atsu, et al., 2006; Bottino, et al., 2005; Gökçe, et al., 2007; Harashima, et al., 2005).

2. Morphological analysis of Er:YAG laser treated enamel and dentin

Etching of enamel with phosphoric acid was first recommended by Buonocore in 1955. (Buonocore, 1955). Resin bonding to tooth ensured by acid etching of enamel and/or dentin with total etch or self-etching techniques and followed by the use of a dentin adhesive (Fusayama, et al., 1979). Phosphoric acid removes the matrix phase of enamel and increases the surface area as well as creating high-energy hydrophilic surface with honey-comb-like structure (Sharpe, 1967; Reynolds, 1975). Acid etching results in dissolution of the hydroxyapatite and enhances the penetration of adhesive monomers (Van Meerbeek, et al., 2003) forming resin tags in situ after polymerization (Barkmeier & Cooley, 1992; Leinfelder, 2001).

Conversely bonding to dentin is more complex due to its hydrated biological structure. To obtain intimate association of adhesive and dentin is hard when dentin is conditioned with total etch technique (Marshall, et al., 1997; Pashley, 1992). Etching dentin results in smear-free surface, open dentinal tubules with widened orifices due to removal of peritubular dentin, increased permeability by the loss mineralized dentin within the collagen matrix and exposed collagen web (Marshall, et al., 1997; Pashley, 1992; Pashley & Carvalho, 1997; Schein, et al., 2003).

Micromechanical retention is still the key factor for bonding to dentin. Monomers containing hydrophilic radicals infiltrate through the collagen fibrils and polymerized to develop the micromechanical retention. Many efforts have been spent to promote this dentin-resin interdiffusion zone, hybrid layer, since its description in 1982 (Nakabayashi, et al., 1982).

Air abrasion has also been introduced for enamel pretreatment by Olsen et al., in 1940. It was used for cavity preparation (Olsen, et al., 1997a). In this method, alumina particles were applied under air pressure to roughen the enamel surface (Zachrisson & Buyukyilmaz, 1993).

Etching dental hard tissues with laser has recently been proposed and may enable strong bonds with the restorative materials. Pulsed Nd:YAG lasers are sometimes used to etch enamel in preparation for bonding of restorative materials but some studies suggest that Nd:YAG etching alone results weaker bonds compared with acid etching (Roberts-Harry, 1992). It was suggested that to use the Nd:YAG laser efficiently for surface roughening a topical absorber must be applied to enamel surfaces and low pulse energies (100 mJ or less) should be used (Roberts-Harry, 1992). SEM evaluation of the surface of Nd:YAG laser treated dentin was partially obliterated due to resolidification of molten dentin with grooves, fissures and concavities but without smear layer (Ariyaratnam, et al., 1999). They also stated that lased dentin surfaces produced a rougher surface compared to untreated dentin. This difference was suggested to maintain the micromechanical interlocking with
the dentin adhesive. It was concluded that although laser irradiation with Nd:YAG laser produced a favorable surface for bonding, the bond strength to dentin did not differ from the conventionally treated dentin.

Both enamel and carious dentine were suggested to be removed with Nd:YAG and excimer lasers without signs of thermal damage (White, et al., 1993; Frentzen, et al., 1992; Arima & Matsumoto, 1993; Wilder-Smith, et al., 1997). When compared with Nd:Yag laser, Ho:YAG laser was shown to remove dental hard tissues more effectively with less cracks (Cernavin, 1995).

Some investigations suggest that CO$_2$ laser etching results in bonds of comparable strength on enamel and higher bond on dentin surfaces, compared to acid etching (Cooper, et al., 1988; Liberman, et al., 1984). Therefore CO$_2$ lasers can be recommended for enamel etching prior to composite restorations and fissure sealants without need of an absorber (Walsh, 1994). However excessive heat generated by some lasers may cause pulpal damage (Akova, et al., 2005). Adequate laser parameters can supply limited pulpal temperature increases within safety limits (Obata, et al., 1999). Controversially CO$_2$ laser at high fluencies and in continuous wave mode may cause cracking, flaking, crater formation, charring, melting and recrystallization of dental hard tissues (Stern, et al., 1972; Boehm, et al., 1997; McCormack, et al., 1995; Malmström, et al., 2001).

Other pulsed lasers whose wavelengths are strongly absorbed by dental hard tissues and hydroxyapatite, e.g. erbium lasers (Er:YAG and Er, Cr:YSGG), can successfully be used for dental hard tissue procedures including conditioning or etching without any side effects. Again no absorber is required (Liberman, et al., 1984; Keller & Hibst, 1989; Burkes, et al., 1992; Wigdor, et al., 1993; Visuri, et al., 1996b).

The water and the hydrated components of dental hard tissues absorb the high energy of erbium lasers and evaporate with micro explosions resulting in particle removal (ablation). (Cardoso, et al., 2008; Esteves-Oliveira, et al., 2007; Tachibana, et al., 2008; Lee, et al., 2007). This thermomechanical effect of erbium lasers on dental hard tissues can vary according to the tissue composition and mainly the water concentration. The mechanism of ablation of dental hard tissues with erbium lasers is still unclear but it was proposed that it takes place by the expansion of subsurface water resulting in microexplosions. This microexplosion induce strong mechanical separation of the calcified tissue (Kayano, et al., 1989). This constitutes the major principle of erbium laser ablation and produce non-uniform tissue removal with ejection of both organic and inorganic tissue microparticles, creating the micro-crater like appearance typical of lased surfaces (Corona, et al., 2007).

Erbium lasers have a shallow thermal penetration depth and can ablaze sound and carious enamel and dentine (Keller & Hibst, 1989; Burkes, et al., 1992; Wigdor, et al., 1993; Visuri, et al., 1996b). Besides rough and irregular surface with sharp edged craters without color changes indicative of thermal damage (burning or carbonization) of surrounding tissues and/or the pulp have been reported. Concave and convex surfaces caused by microablation have been observed (Harashima, et al., 2005; Oelgiesser, et al., 2003). Er:YAG laser with appropriate parameters proposed to can selectively remove enamel hydroxyapatite crystals resulting in irregular surface that would enhance the micromechanical retention (Hibst & Keller, 1989; Hossain, et al., 1999).
Sasaki, et al., (2008) made a structural analysis of acid and Er:YAG laser etched enamel. They stated that acid etching exhibited a more homogenous etching pattern whereas Er:YAG alone showed areas of ablation. Er:YAG laser irradiation followed by acid etching resulted in more homogenous surface pattern than the only lased surfaces.

Harashima, et al., (2005) reported that cavities prepared by Er:YAG laser showed characteristic rough surface similar to an acid etched surface with open dentinal tubules and stripped surfaces. They also stated very clean surfaces, almost free of debris when the laser tip was aligned perpendicular to the surface. Scratched appearance with interspersed open dentinal tubules at areas covered by melted surfaces was found with angulated laser application (Harashima, et al., 2005). Unlike acid etching it was shown that the collagen fibrils were not found forming a porous network responsible for the increased porosity of dentin surface and subsurface. The morphological analysis of resin-dentin interface of acid etched dentin revealed triangular hybridization with resin tags in different lengths at the transition between peri- and intertubular dentin. But little or no hybridization zones with fewer and thinner tags at the intertubular dentin areas could be observed due to scarcity and discontinuity of the interdiffusion area at the resin-dentin interface (Schein, et al., 2003).

Literature review also states crater formations, mineral meltdowns and enamel melting, cracks, fissuring in enamel and smooth edged voids (Frentzen & Koort, 1992; Olsen et al., 1997b). Parameter factors and wavelength specificity relate to the degree of change that can be induced to enamel. Varying pulse width, pulse mode and spot size can produce significant changes in enamel and dentin surface morphology (Frentzen & Koort, 1992).

Erbium lasers also denatures the organic content and reduces the solubility of hydroxyapatite (Keller & Hibst, 1989; Hibst & Keller, 1989; Bader & Krejci, 2006). The interaction of erbium lasers with dental hard tissues results in negatively effected bond between the composite resins and dentin and collagen fibrils (Moretto, et al., 2010; Ceballo, et al., 2002; Ramos, et al., 2010, Oliveira, et al., 2010). Carvalho, et al., (2011) suggested that removal of laser irradiated dentin with phosphoric acid gel and sodium hypochlorite had increased the bond strength to dentin.

In a recent study phosphoric acid etching of enamel was compared with Er:YAG laser and Er:YAG laser+acid etching, and it was concluded that Er:YAG laser+acid group exhibited the highest bond strength, followed by acid and laser groups. The lower bond strength with only laser group was attributed to the non-homogenous laser application leaving untouched areas on the surface. Laser application followed by acid etching effectively conditioned the non-lased spots remained within the irradiated area (Sasaki, et al., 2008).


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Treating dentin erbium lasers (Er:YAG and Er,Cr:YSGG) creates a rough, smear layer-free surface with open dentinal tubules. SEM observations of Carvalho, et al., (2011) revealed irregular and rugged dentinal surfaces, following Er,Cr:YSGG laser. Harashima, et al., (2005) observed smaller width and stripped surfaces on the cavities prepared by Er:YAG laser. They may also cause fissures and cracks that can be considered as drawbacks of using erbium lasers for surface pretreatment (Aoki, et al., 1998; Hossain, et al., 1999; De Munck, et al., 2002; De Oliveira, et al., 2007; Moretto, et al., 2010). Increase in acid resistance of dental hard tissues after laser irradiation was also been reported by some authors (Fried, et al., 1996; Hossain, et al., 2000; Apel, et al., 2002; Liu, et al., 2006).

SEM evaluation of Er:YAG laser treated enamel and dentin revealed different surface morphologies in accordance with literature reviewed depending on the laser parameters.

2.1 Morphological analysis of Er:YAG laser treated enamel

Fig. 1. Enamel. 100 mj. 10 Hz. With water cooling. Honey-comb appearance can be seen but not throughout the surface which is due to non-homogenous application of the laser.

Fig. 2. Enamel. 100 mj. 10 Hz. With water cooling. Honey-comb appearance can be seen on the surface similar to acid etching.
Fig. 3. Enamel. 100 mj. 10 Hz. With water cooling. Higher magnification of the surface in Fig. 2. No signs of thermal damage. Honey-comb appearance.

Fig. 4. Enamel. 250 mj. 10 Hz. With water cooling. Serrated surface with honey-comb appearance.

Fig. 5. Enamel. 500 mj. 10 Hz. With water cooling. Interprismatic matrix has been removed. Similar to acid etching but some melting points probably due to repeated shots at the same point can be observed.
Fig. 6. Enamel. 600 mj. 10 Hz. Without water cooling. Layered enamel surface possibly due to dehydration of enamel during laser application.

Fig. 7. Enamel. 750 mj. 10 Hz. Without water cooling. Higher magnification of the previous Fig. Layered enamel surface.

Fig. 8. Enamel. 800 mj. 5 Hz. Without water cooling. Melted and resolidified enamel. This texture is highly acid resistant.
Fig. 9. Enamel. 1000 mj. 10 Hz. Without water cooling. Rose-bud like appearance. Clear evidence of over destruction of enamel with high energy intensity. Enamel lost its integrity in layers around the lased point. (The crack at midline is a result of dehydration during preparation of the specimen for SEM evaluation).

Fig. 10. Enamel. 1000 mj. 10 Hz. Without water cooling. Similar appearance with Fig. 13. Overdestructed and layered surface as a result of excessively heated enamel.

2.2 Morphological analysis of Er:YAG laser treated dentin

Fig. 11. Dentin. 250 mj. 10 Hz. Without water cooling. Swollen dentin orifices.
Fig. 12. Dentin. 400 mj. 10 Hz. Without water cooling. Cavitation with charring. (The crack at midline is a result of dehydration during preparation of the specimen for SEM evaluation).

Fig. 13. Dentin. 250 mj. 10 Hz. With water cooling. Partially open dentinal tubules with crater formations.

Fig. 14. Dentin. 500 mj. 10 Hz. Without water cooling. Pop-corn like appearance. One exploded (right) and one over swollen dentin orifices. Evidence of thermal destruction of dentin.
Fig. 15. Dentin. 500 mj. 5 Hz. With water cooling. Intertubular apparent evidence of intertubular dentin being affected dramatically by laser. (The crack on the right is a result of dehydration during preparation of the specimen for SEM evaluation)

Fig. 16. Dentin. 250 mj. 5 Hz. With water cooling. Nearly all dentinal tubules are open. Adequate surface for bonding procedures. Stratified surface due to non-homogenous application of laser. Calcospherite areas which are usually seen following Na(OH) were observed.

Fig. 17. Dentin. 250 mj. 5 Hz. With water cooling. Higher magnification of the surface in Fig. 16. No signs of thermal damage. No melted and swollen dentin. All dentinal tubules are open. Adequate surface for bonding procedures.
Fig. 18. Dentin. 250 mj. 5 Hz. With water cooling. Higher magnification of the surface in Fig. 17. No signs of thermal damage.

3. Morphological analysis of Er:YAG laser treated all-ceramic materials

A new class of dental framework materials have been introduced to the market for crown and fixed partial denture fabrication such as high-aluminium trioxide (alumina) ceramics, leucite reinforced feldspathic ceramics, castable glass-ceramics, machining and CAD/CAM ceramic systems and yttrium tetragonal zirconia polycrystal (Y-ZTP; zirconia) (Atsu, et al., 2006; Amaral, et al., 2006; Bottino, et al., 2005; Kim, et al., 2005; Kern & Wegner, 1998). Alumina and zirconia demonstrate high clinical success due to their high crystalline content and are potential substitutes for traditional materials (Cavalcanti, et al., 2009a; Jacobsen, et al., 1997; Haselton, et al., 2000; Toksavul & Toman, 2007; Fradeani & Redemani, 2002).

The tetragonal to monoclinic phase transformation capability of zirconia results in high mechanical properties (Guazzato, et al., 2004). External stresses such as sandblasting, grinding, impact, and thermal aging can trigger this phase transformation mechanism (Karakoca & Yılmaz, 2009).

The clinical success and survival rates of these restorations depend on several factors such as cementation procedure. To maintain a micromechanical bond, a key factor between restoration and the resin, luting surfaces of the restorations should be conditioned (Awliya, et al., 1998; Özcan, et al., 2001). To achieve reliable adhesion to these new materials, surface pre-treatments usually followed by silanization are required (Atsu, et al., 2006; Amaral, et al., 2006; Bottino, et al., 2005; Kim, et al., 2005; Kern & Wegner, 1998).

To obtain high mechanical bond strength to newer restorations, the inner surfaces are roughened by numerous techniques to increase the luting surface area. Among several methods that have been investigated for surface modification dental restorative materials, grinding, abrasion with diamond rotary instruments, airborne particle abrasion with aluminum oxide particles (sandblasting), chemical etching with different concentrations of hydrofluoric acid (HF), silica coating (Cojet, Rocatec), Silicoater MD, PyrosilPen silanization, selective infiltration-etching technique and combinations of any of these methods are the most common conditioning techniques prior to luting procedures (Amaral, et al., 2006; De Oyague, et al., 2009; Özcan, et al., 2001; Özcan, 2002; Kern & Thompson, 1994; Aboushelib, et
al., 2007). Although surface treatments are used to micromechanical retention, they might affect the mechanical properties of zirconia (Sato, et al., 2008).

For chemical etching, different concentrations of HF acid, acidulated phosphate fluoride and ammonium bifluoride are used to condition the restorations (Blatz, et al. 2003; Clauss, 2000; Janda, et al. 2003). Etching dissolves the low fusing glass matrix exposing the crystalline structure and creates a micromechanically retentive surface but also promotes hydroxyl group formation on the etchable ceramic materials (Matinlinna & Vallitu, 2007; Özcan, 2003; Van Noort, 2002a; ÖZcan, et al., 2001). But some new materials such as zirconia and alumina are non-etchable because of they do not have glassy phase at the crystalline border and it is difficult to form microretentive surfaces to obtain strong and durable bonds with chemical etching techniques (Blatz, et al., 2003; Clauss, 2000; Janda, et al., 2003; Awliya, et al., 1998). Therefore different surface conditioning methods such as sandblasting and silica coating have been suggested for surface pretreatments of alumina and zirconia frameworks to modify the surface properties (Della Bona, et al., 2004; Phark, et al., 2009; Ersu, et al., 2009; Jacobsen, et al., 1997).


Large abrasive particles result in rougher surface since the abrasion of the surface increases in proportion to the square of the diameter of the particle. Particle size variations and and the high pressure during sandblasting may cause flaws and phase transformation that expedites micro-crack formation and lead to altered mechanical properties of zirconia (Zhang, et al., 2004; Zhang, et al., 2006). Mechanical grinding and sandblasting may create subcritical microcracks and phase transformation within zirconia surface which might negatively affect the mechanical properties (Karakoca & Yılmaz, 2009; Ayad, et al., 2008).

Sandblasting is not recommended to roughen In-Ceram Zirconia frameworks as the aluminum oxide particles used to condition the surface have a hardness similar to that of the aluminum oxide crystals present in the target material (Borges, et al., 2003). Alternatively use of synthetic diamond particles 1-3 μm in size have been advocated to roughen the aluminous ceramics (Sen, et al., 2000).

Another method to increase the surface energy of ceramic materials is tribochemical silica coating that is based on forming a SiO₂ layer followed by silane application with accelerated silica coated alumina particles on to the ceramic surface, including non-etchable alumina and zirconia (Matinlinna & Vallitu, 2007; Kramer, et al., 1996; Sindel, et al., 1996; Özcan, 2002). Silica coating method also provides micromechanical retention like sandblasting and silica deposition on the luting surface (Kern & Thompson, 1995; Matinlinna & Vallitu, 2007; ÖZcan, et al., 2001). In a recent study AFM results revealed irregular and heterogeneous surfaces following silica coating and sandblasting of zirconia with the formation of high peaks and shallows while SEM observations showed microretentive grooves in conjunction with Atomic Force Microscope (AFM) results (Subaşi & İnan, 2011).
In addition to currently used conditioning methods, laser-induced modifications of dental materials have also been studied. Lasers have been proposed to modify the surface of materials in relatively safe and easy means (Ersu, et al., 2009; Gökçe, et al., 2007; Akova, et al., 2005; Spohr, et al., 2008; Cavalcanti, et al., 2009b; Jacobsen, et al., 1997). Implant surfaces treated with lasers exhibit high degree of purity with adequate surface roughness (Gaggl, et al., 2000; Cho & Jung, 2003).

Among the several applications of lasers, surface conditioning for bonding have also been reported. Various laser types such as Nd:YAG, Er:YAG, Er,Cr:YSGG and CO₂ have been studied for surface alterations of dental materials (Convissar & Goldstein, 2001). But only limited studies are available on the laser treatment of all ceramic materials (Ersu, et al., 2009; Gökçe, et al., 2007; Akova, et al., 2005; Cavalcanti, et al., 2009b; Jacobsen, et al., 1997; Cavalcanti, et al. (2009a).

Ceramics do not effectively absorb some certain wavelengths such as 1064 nm (Nd:YAG). To increase the energy absorption of this laser the surface of ceramic material can be covered with graphite powder prior to laser irradiation. During laser application the graphite is removed from the surface with microexplosions (Spohr, et al., 2008).

Some lasers are also used for other applications such as forming a glazed surface layer on ceramics, the removal of resin composite filling materials, laser welding of ceramics and metal alloys, including titanium, and increasing the corrosion resistance of metal alloys (Ersu, et al., 2009; Schmage, 2003). Focussed CO₂ laser causes in conchoidal tears (result of surface warming) on ceramic surface that provides mechanical retention between resin composite and ceramics. But sudden temperature changes could create internal tensions that might affect the bond strength (Ersu, et al., 2009). The authors concluded that CO₂ laser surface modification demonstrated higher bond strength than control, sandblasted and chemical etching.

Results of studies that compared the bond strength of resins to CO₂ laser and chemically etched zirconia vary. Obata, et al., (1999) stated that laser etching produced lower bond strength compared to acid etching whereas Ural, et al., (2010) proposed higher bond strength. They attribute the high bond strength values to power levels of the laser used in their study. Increased power settings caused micro-cracks and high bond strength (Ural, et al., 2010).

Watanabe, et al., (2009) suggested that Nd:YAG laser irradiation improved the mechanical properties of cast titanium. Nd:YAG laser as an etchant was also used to enhance the bond strength of low-fusing ceramic to titanium (Kim & Cho, 2009).

Nd:YAG laser was also used to roughen In-Ceram Zirconia and feldspathic ceramic (Li, et al., 2000; Spohr, et al., 2008). Li, et al., (2000) reported that SEM images of Nd:YAG laser applied specimens was favourable to mechanical retention between the feldspathic ceramic and the resin cement and both laser and HF acid etched groups exhibited same shear bond strength. Nd:YAG laser treatment of In-Ceram Zirconia caused surface changes characterized with material removal due to the micro-explosions resulting in formation of voids and fusing and melting of the most superficial ceramic layer followed by solidification to a smooth blister-like surface (Spohr, et al., 2008). Nd:YAG laser irradiation of zirconia causes color change to black with many cracks and reduced oxygen content (Noda, et al., 2010).
Recently roughening capacity of the Er:YAG laser for the inner surfaces of the lithium disilicate material has been introduced (Gökçe, et al., 2007). Ceramic specimens laser etched with low energy levels exhibited similar bond strength that of chemically etched specimens. But as the energy level increased bond strength values decreased dramatically. They concluded that their results could be explained by insufficient micro depths of the irregularities formed by high Er:YAG laser power settings, which resulted in limited penetration of silane and low bond strength. Higher power settings resulted in low bond strengths which might be due to over destruction (disassociation) of the crystal and/or matrix phases or heat damaged layer which was poorly attached to the infra layers or increased luting agent thickness due to craters caused by laser pulses (Gökçe, et al., 2007).

Erbium lasers are absorbed mainly by water and their absorption by water-free materials are compromised. To increase the effect of erbium lasers, covering the zirconia surfaces with graphite or hydroxapatite powder was recommended (Cavalcanti, et al., 2009b). Akın, et al., (2011) irradiated zirconia surface with Er:YAG laser and found increased surface roughness and surface irregularities compared to the untreated specimens. The authors used low power settings with water cooling and did not observe microcracks. They concluded that altering the zirconia surface with Er:YAG laser increased the shear bond strength of ceramic to dentin and found to be effective for decreasing microleakage in the adhesive-ceramic interface. Their results were in accordance with the study of Cavalcanti, et al. (2009a). Erdem & Erdem, (2011) studied the effect of Er:YAG laser irradiation with water cooling on zirconia and unlike forementioned researchers they suggested that laser treatment decreased the bond strength of resin composite to zirconia framework. They observed microcracks throughout the surface in contrast with Akın, et al., (2011). They attributed the low bond strength values to excessively affected surfaces and crack formation which was possibly a result of laser irradiation. Stepped local temperature changes and pressurized water followed by thermocycling could be responsible for low temperature degradation of zirconia resulting in low bond strengths (Erdem & Erdem, 2011). They might have also induced phase transformation (Cavalcanti, et al., 2009a). The microcrack formation and sizes enlarged as the laser intensity increased (Cavalcanti, et al., 2009b). Stübinger, et al., (2008) demonstrated that Er:YAG and CO\textsubscript{2} lasers adversely affected the zirconia implant surfaces. They found crack formations up to 100 μm depth and large grains in blackened areas under SEM evaluation. Excessive power settings shown to be detrimental to zirconia and their use for zirconia surface conditioning was questionable (Cavalcanti, et al. 2009b; Navarro, et al., 2010).

Subaşı & İnan, (2011), evaluated the Er:YAG laser treated zirconia with AFM and SEM. AFM and SEM results of lased surfaces revealed similar texture to that of the control group with the exception that sharp peaks formations of the lased surfaces. Cavalcanti, et al. (2009b) also demonstrated that increased laser energy levels increased surface roughness of zirconia. Melting, excessive loss of mass, and the presence of smooth areas surrounded by cracks were observed. Lower energy intensities (200 mj) had milder effect with smaller cracks along with melting, solidification and color changes without loss of structure compared to higher intensities (400 and 600 mj) (Cavalcanti, et al., 2009b). 200 mj irradiation also provided alterations similar to sandblasting. Effect of Nd:YAG laser (100 mj) and Er:YAG laser (200 mj) exhibited similar topographies although the Nd:YAG laser had a totally different target interaction compared with the Er:YAG laser (Da Silveira, et al., 2005; Cavalcanti, et al., 2009b).
There is no consensus about energy levels of Er:YAG laser that could be used to modify the zirconia surface. 400 mj at 10 Hz (Subaşı & İnan, 2011), 150 mj at 10 Hz (Akn, et al., 2011), 200 mj at 10 Hz (Erdem & Erdem, 2011), 200 mj at 10 Hz (Cavalcanti, et al., 2009a); 200 mj, 400 mj, 600 mj at 10 Hz (Cavalcanti, et al., 2009b), 300 mj at 10 Hz (Şen & Ceylan, 2010) were chosen to roughen zirconia surfaces. Besides different methods have been chosen to evaluate the bond strength and surface topography. Therefore it is difficult to compare the results of the studies reviewed.

3.1 Morphological analysis of Er:YAG laser treated and hydrofluoric acid etched Li-disilicate material

SEM evaluations of 9.5% Hydrofluoric acid and Er:YAG laser Li-disilicate material revealed different surface morphologies, depending on the surface conditioning methods.

3.1.1 SEM evaluation before shear bond strength testing

Fig. 19. The untreated surface showing intact glassy phase without any apparent crystals.

Fig. 20. 9.5% HF, 30 seconds. The surface has both apparent Li-disilicate crystals and glassy matrix. Glass matrix phase could not be completely removed if not applied homogenously and might lead to ill penetration of silane and the adhesive.
Fig. 21. 9.5% HF, 30 seconds. Visible Li-disilicate crystals. Completely removed glassy matrix. Appropriate etching pattern and surface for adhesive cementation (Gökçe et al., 2007).

Fig. 22. Er:YAG laser, 300 mj, 10 Hz. Affected (a) and unaffected (u) areas of lased surface.

Fig. 23. Er:YAG laser, 300 mj, 10 Hz. Irregular Li-disilicate crystals in smaller sizes (Gökçe et al., 2007).
Fig. 24. Er:YAG laser, 600 mJ, 10 Hz. Increased surface irregularities with severely affected and disassociated Li-disilicate crystals (Gökçe et al., 2007).

Fig. 25. Er:YAG laser, 900 mJ, 10 Hz. Severely affected and disassociated Li-disilicate crystals (Gökçe et al., 2007).

Fig. 26. Er:YAG laser, 1000 mJ, 10 Hz. Melted and resolidified surface. This layer is poorly attached to the underlying intact phase.
3.1.2 SEM evaluation after shear bond strength testing

SEM evaluation following shear bond strength of the untreated, HF acid etched and Er:YAG laser conditioned Li-Disilicate material exhibited different failure modes, indicatives of adhesion of the bonding agent and the luting cement (Variolink II).

Fig. 27. Er:YAG laser, 1000 mj, 10 Hz. Higher magnification of the surface in Fig. 26.

Fig. 28. Untreated ceramic surface. Adhesive failure inbetween the ceramic and the cement. No rough surfaces were noted on the ceramic (Gökçe et al., 2007).

Fig. 29. 9.5% HF, 30 seconds. Good adhesion at the cement-ceramic interface with increased surface roughness. Mainly cohesive failures within the cement (Gökçe et al., 2007).
Fig. 30. Er:YAG laser, 300 mJ, 10 Hz. No visible cement on the margins, while a cement remnant at the center of the specimen with adhesive+cohesive failures were observed (Gökçe et al., 2007).

Fig. 31. Er:YAG laser, 600 mJ, 10 Hz. Partially delaminated cement surfaces can be observed with adhesive failures (Gökçe et al., 2007).

Fig. 32. Er:YAG laser, 900 mJ, 10 Hz. Adhesive failure between cement and ceramic. Decreased irregularities and severe effects of laser on the ceramic surface (Gökçe et al., 2007).
3.2 Morphological analysis of sandblasted and Er: YAG laser-roughened alumina material

Fig. 33. Untreated In-Ceram Alumina (Şen, 2010).

Fig. 34. In-Ceram Alumina. Airborne particle abrasion (110μm Al₂O₃). Affected and rougher surface compared to untreated surface with shallow pits (Şen, 2010).

Fig. 35. In-Ceram Alumina. Er:YAG laser, 150 mj at 10 Hz with water cooling. Locally affected points on the surface due to non-homogenous application of the laser (Şen, 2010).
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3.3 Morphological analysis of sandblasted, silica coated and Er: YAG laser-roughened zirconia

3.3.1 SEM evaluation before shear bond strength testing

Fig. 36. In-Ceram Alumina. Er:YAG laser, 250 mj at 10 Hz with water cooling. Generalized effect of laser rougher surface compared to untreated and 150 mj laser applied surfaces (Şen, 2010).

Fig. 37. In-Ceram Alumina. Er:YAG laser, 400 mj at 10 Hz with water cooling. Serrated and smoothened surface by resolidification of melted areas. This resolidified layer might be poorly attached to the underlying material (Şen, 2010).

Fig. 38. Untreated zirconia. 2000x (left) and 5000x (right) magnifications (Erdem & Erdem, 2011).
Fig. 39. Sandblasted (particle size 110 µm) zirconia. 2000x (left) and 5000x (right) magnifications. Increased roughness compared to untreated zirconia (Erdem & Erdem, 2011).

Fig. 40. Sandblasted (particle size 180 µm) zirconia. 500x magnification. Similar texture with the 110 µm air abraded surface.

Fig. 41. Silica coated (Rocatec Pre110 µm and Rocatec Soft 30 µm) zirconia. 2000x (left) and 5000x (right) magnifications. Increased roughness similar to sandblasting and silica deposition on the surface can be observed (Erdem & Erdem, 2011).
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Fig. 42. Silica coated (Rotatec Pre110 µm and Rotatec Soft 30 µm) zirconia. 500x magnification. Increased roughness similar to particle abrasion with aluminum oxide (Sen, 2010).

Fig. 43. Graphite coated and lased (200 mj, 10 Hz) zirconia. 2000x (left) and 5000x (right) magnifications. Rough and severely affected appearance with irregular surface (Sen, 2010) with micro cracks (Erdem & Erdem, 2011).

3.3.2 SEM evaluation after shear bond strength testing

Fig. 44. Untreated zirconia. 2000x (first line) and 5000x (second line) magnifications. No cement retention was observed on untreated zirconia (Erdem & Erdem, 2011).
Fig. 45. Sandblasted (particle size 110 µm) zirconia. 2000x (first line) and 5000x (second line) magnifications. Two of the cements tested exhibited both adhesive and cohesive failures. (Z: Zirconia, C: Cement) (Erdem & Erdem, 2011).

Fig. 46. Silica coated (Rocatec Pre110 µm and Rocatec Soft 30 µm) zirconia. 2000x (first line) and 5000x (second line) magnifications. Similar results with sandblasting was observed after shear bond strength testing (Z: Zirconia, C: Cement) (Erdem & Erdem, 2011).

Fig. 47. Graphite coated and lased (200 mj, 10 Hz) zirconia. 2000 (first line) and 5000 (second line) magnifications. Adhesive failures observed in all cement groups. No cement retention on any of the groups. (X: severely affected area, C: Cement) (Erdem & Erdem, 2011).
4. Conclusion

There are many techniques to condition dental hard tissues and luting surfaces of indirect restorations prior to bonding. Operators find it difficult to decide which technique offers better results, and are also uncertain about the factors that might influence their techniques of choice. However micromechanical retention of luting materials to acid etched conditioned dental hard tissues is currently seems to be the most successful and reliable approach for dental bonding. But surface characteristics of Er:YAG lased enamel and dentin are responsible for considering this surface adequate for resin bonding.

It is assumed that the ablation rate of lasers on the dental materials is strongly influenced by the differences in composition and microstructure of the material and the presence of water. In spite of its great potential for ablation, Er:YAG laser effectiveness and safety is also directly related to adequate setting parameters. Power settings, frequency and durations of laser irradiation play an important role to obtain optimum bond strength and roughness values.

Future studies are needed to evaluate the superficial and sub-superficial layers of irradiated dental hard tissues and materials in order to develop new agents that can interact properly with lased substrate. In my opinion, in the near future, 9.6 μm CO2 laser with an adequate delivery system that has the absorption peak in hydroxyapatite will replace many dental hard tissue lasers, which are currently being used. In the presented chapter, the morphological assessment of Er:YAG lased dental hard tissues and materials have been discussed under the light of the current literature.

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Today, an individual would be hard-pressed to find any science field that does not employ methods and instruments based on the use of fine focused electron and ion beams. Well instrumented and supplemented with advanced methods and techniques, SEMs provide possibilities not only of surface imaging but quantitative measurement of object topologies, local electrophysical characteristics of semiconductor structures and performing elemental analysis. Moreover, a fine focused e-beam is widely used for the creation of micro and nanostructures. The book’s approach covers both theoretical and practical issues related to scanning electron microscopy. The book has 41 chapters, divided into six sections: Instrumentation, Methodology, Biology, Medicine, Material Science, Nanostructured Materials for Electronic Industry, Thin Films, Membranes, Ceramic, Geoscience, and Mineralogy. Each chapter, written by different authors, is a complete work which presupposes that readers have some background knowledge on the subject.

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