Effects of Er:YAG Laser Irradiation on Dental Hard Tissues and All-Ceramic Materials: SEM Evaluation

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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 & Hibst, 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; Reynold, 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 (Nakayabashi, 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 & Buyukyılmaz, 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 ablate 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).

On the other hand some authors reported that the microretentive pattern resulting from laser irradiation could be favorable to bonding procedures (Hossain, et al., 2001; Li, et al., 1992; Visuri, et al., 1996a). Some studies suggest that laser irradiated dentinal tissue resulted in lower bond strength than does non-irradiated dentin. Visuri, et al. (1996a) reported a significantly higher shear bond strength of composite to dentin prepared with an Er:YAG laser. In contrast, Sakakibara, et al. (1998), Ceballo, et al. (2002) and Dunn, et al. (2005) reported a decrease in bond strength to laser-irradiated dentin, and Armengol, et al. (1999) and Kataumi, et al. (1998) found no difference between laser- irradiated and non-irradiated specimens.

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

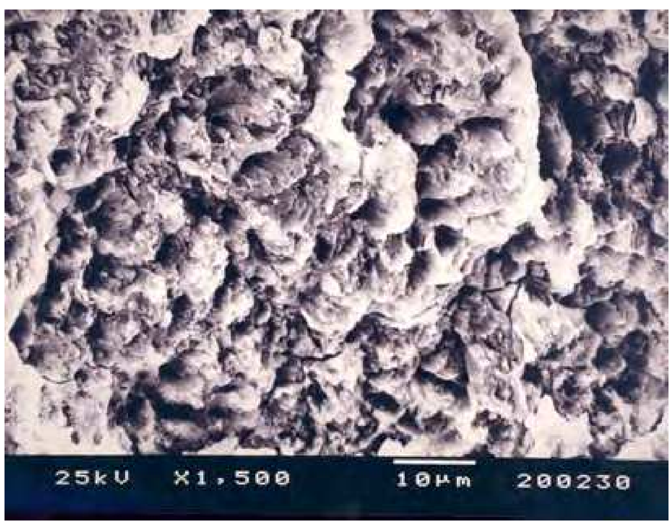


Fig. 1. Enamel. 100 mj. 10 Hz. With water cooling. Honey-comb appearance can be seen but not throughout the surface which is due to non-homogenous application of the laser.

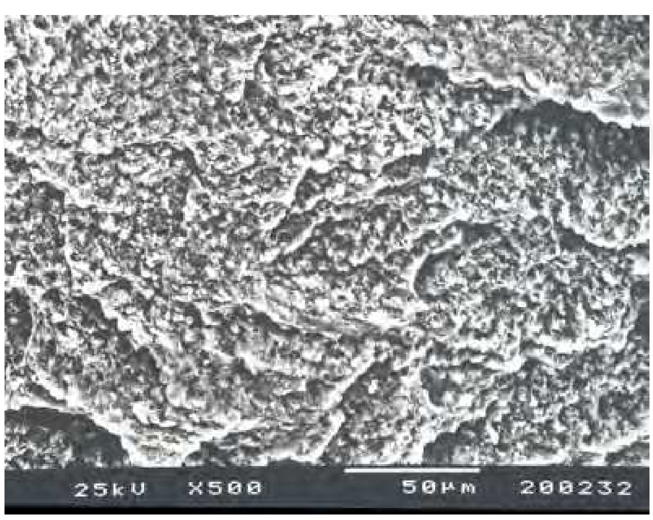


Fig. 2. Enamel. 100 mj. 10 Hz. With water cooling. Honey-comb appearance can be seen on the surface similar to acid etching.

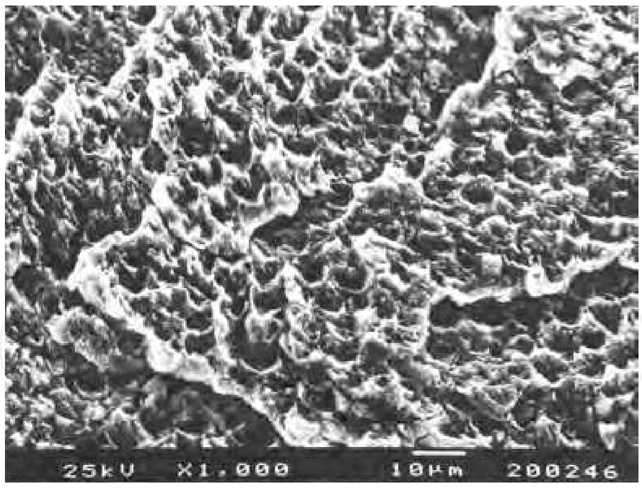


Fig. 3. Enamel. 100 mj. 10 Hz. With water cooling. Higher magnification of the surface in Fig. 2. No signs of thermal damage. Honey-comb appearance.

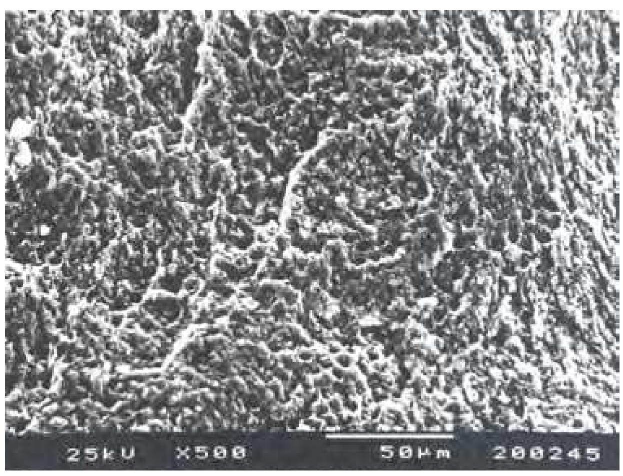


Fig. 4. Enamel. 250 mj. 10 Hz. With water cooling. Serrated surface with honey-comb appearance.

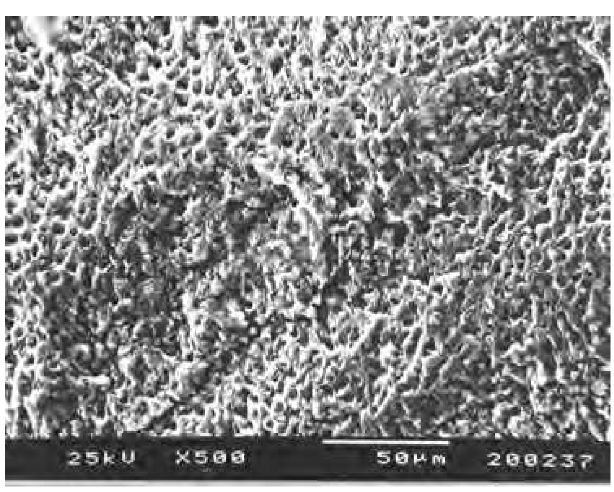


Fig. 5. Enamel. 500 mj. 10 Hz. With water cooling. Interprismatic matrix has been removed. Similar to acid etching but some melting points probably due to repeated shots at the same point can be observed.

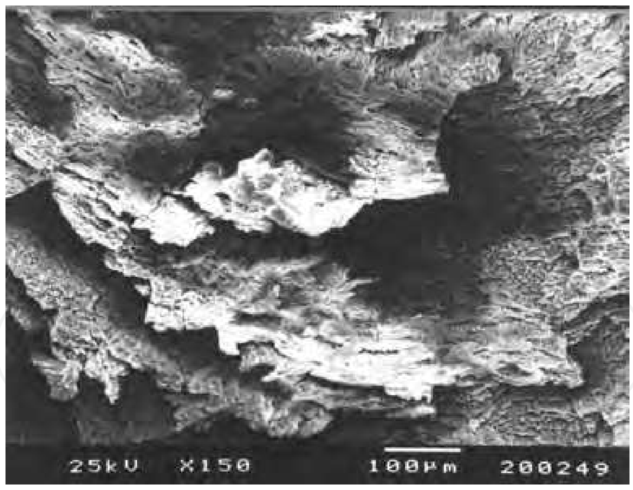


Fig. 6. Enamel. 600 mj. 10 Hz. Without water cooling. Layered enamel surface possibly due to dehydration of enamel during laser application.

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.

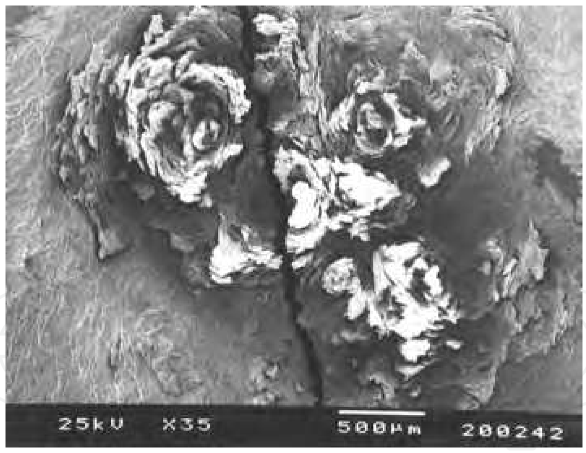


Fig. 9. Enamel. 1000 mj. 10 Hz. Without water cooling. Rose-bud like appearance. Clear evidence of over destruction of enamel with high energy intensity. Enamel lost its integrity in layers around the lased point. (The crack at midline is a result of dehydration during preparation of the specimen for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

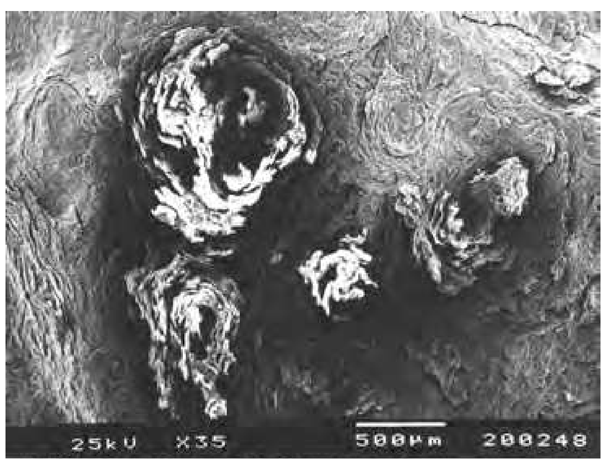


Fig. 10. Enamel. 1000 mj. 10 Hz. Without water cooling. Similar appearance with Fig. 13. Overdestructed and layered surface as a result of excessively heated enamel.

2.2 Morphological analysis of Er:YAG laser treated dentin

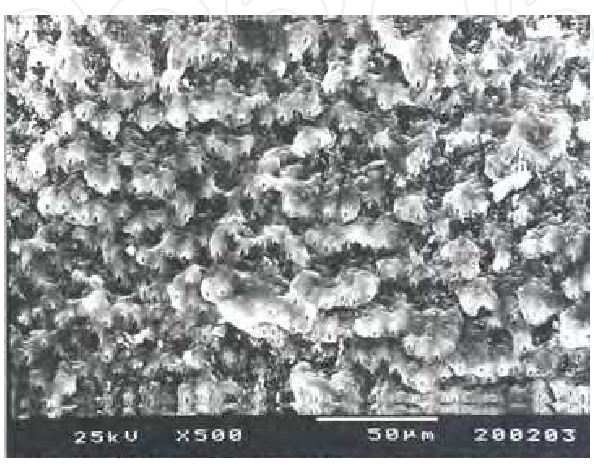


Fig. 11. Dentin. 250 mj. 10 Hz. Without water cooling. Swollen dentin orifices.

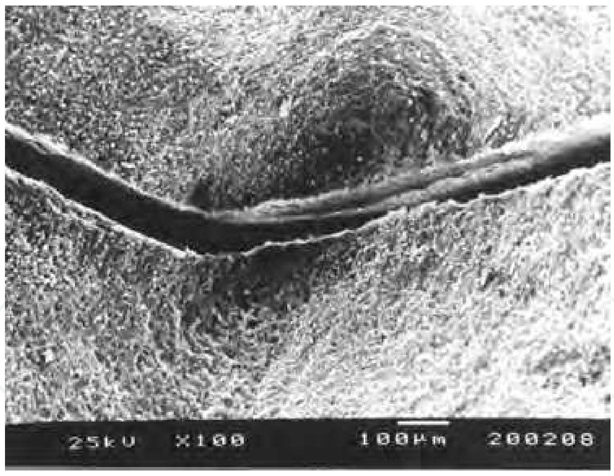


Fig. 12. Dentin. 400 mj. 10 Hz. Without water cooling. Cavitation with charring. (The crack at midline is a result of dehydration during preparation of the specimen for SEM evaluation).

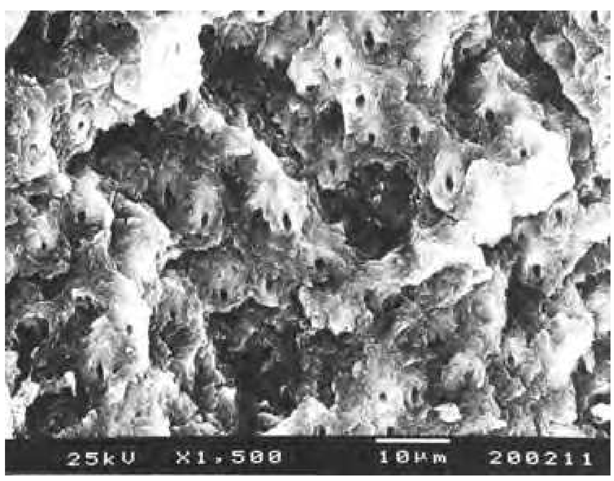


Fig. 13. Dentin. 250 mj. 10 Hz. With water cooling. Partially open dentinal tubules with crater formations.

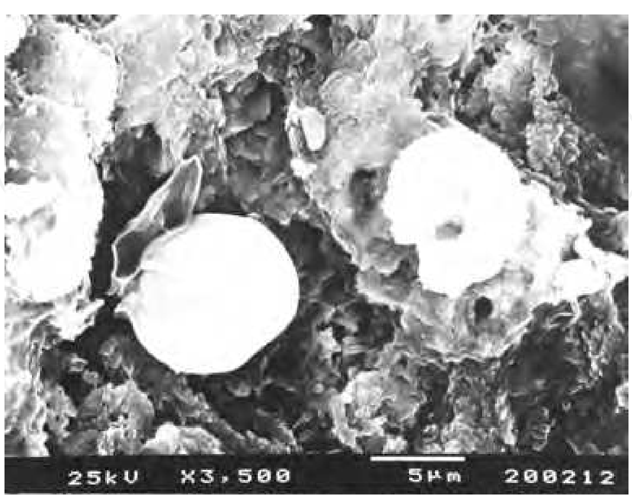


Fig. 14. Dentin. 500 mj. 10 Hz. Without water cooling. Pop-corn like appearance. One exploded (right) an done over swollen dentin orificies. Evidence of thermal destruction of dentin.

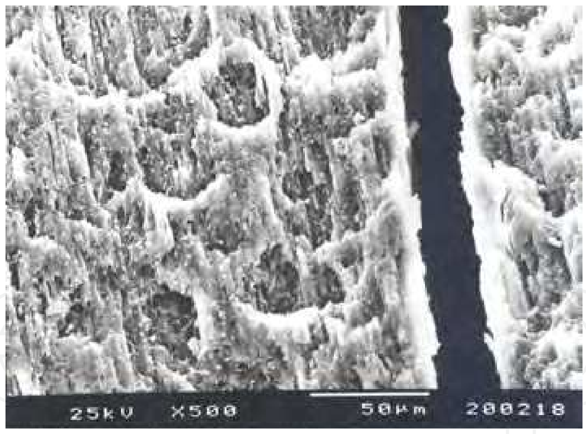


Fig. 15. Dentin. 500 mj. 5 Hz. With water cooling. intertubular Apperent evidence of intertubular dentin being affected dramatically by laser. (The crack on the right is a result of dehydration during preparation of the specimen for SEM evaluation)

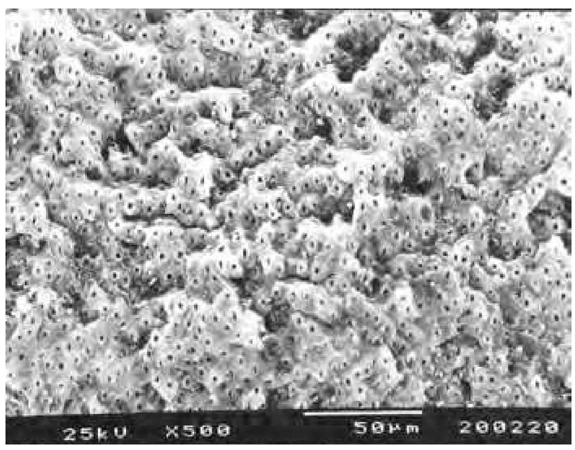


Fig. 16. Dentin. 250 mj. 5 Hz. With water cooling. Nearly all dentinal tubules are open. Adequate surface for bonding procedures. Stratified surface due to non-homogenous application of laser. Calcospherite areas which are usually seen following Na(OH) were observed.

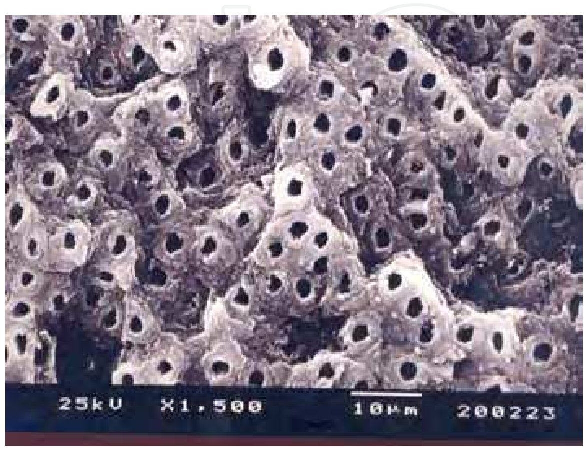


Fig. 17. Dentin. 250 mj. 5 Hz. With water cooling. Higher magnification of the surface in Fig. 16. No signs of thermal damage. No melted and swollen dentin. All dentinal tubules are open. Adequate surface for bonding procedures.

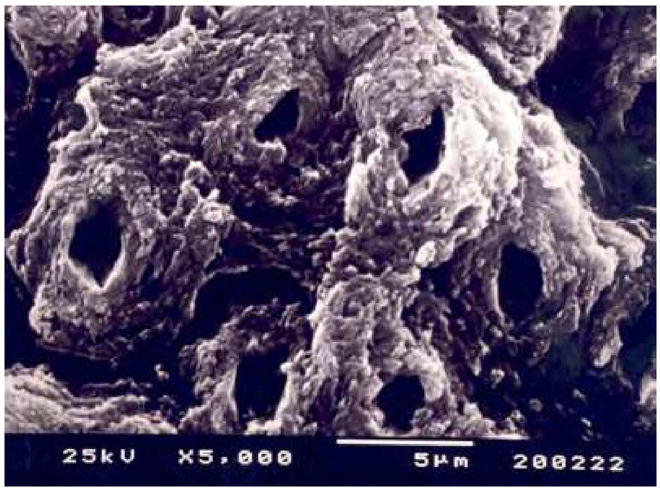


Fig. 18. Dentin. 250 mj. 5 Hz. With water cooling. Higher magnification of the surface in Fig. 17. No signs of thermal damage.

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 tetrogonal 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 cristalline 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 succes 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 cristalline 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 cristalline 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).

Different sizes of alumina particles between 25 and 250 µm are used (Blatz, et al., 2003; Kern & Wegner, 1998; Hummel & Kern, 2004; Curtis, et al., 2006). Sand blasting the surface with aluminum oxide particles cleans the ceramic surface and creates adequate bonding with micromechanical mechanisms to alumina- and zirconia based frameworks (Matinlinna & Vallitu, 2007; Phark, et al., 2009; Blatz, et al., 2003; Kern & Wegner, 1998; Hummel & Kern, 2004; Blatz, et al., 2004). The abrasive process removes loose contaminated layers, increases surface area and improves the wettability (Amaral, et al., 2006; Kümbüloğlu, et al., 2006).

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 inrease the surface energy of ceramic materials is tribochemical silica coating that is based on forming a SiO_2 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 conjuction with Atomic Force Microscope (AFM) results (Subaşı & 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 CO_2 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 CO_2 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 CO_2 laser surface modification demonstrated higher bond strength than control, sandblasted and chemical etching.

Results of studies that compared the bond strength of resins to CO_2 laser and chemically etched zirconia vary. Obata, et al., (1999) stated that laser etching produced lower bond strength compared to acid ecthing 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 fovarable 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 di-silicate material has been introduced (Gökçe, et al., 2007). Ceramic specimens laser etched with low energy levels exhibited similar bond strength that of chemicaly etched specimens. But as the energy level increased bond strength values decreased dramtically. 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 microlekage 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 resarchers 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 degredation 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_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 deterious 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 (Akın, 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 hydroflouric 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

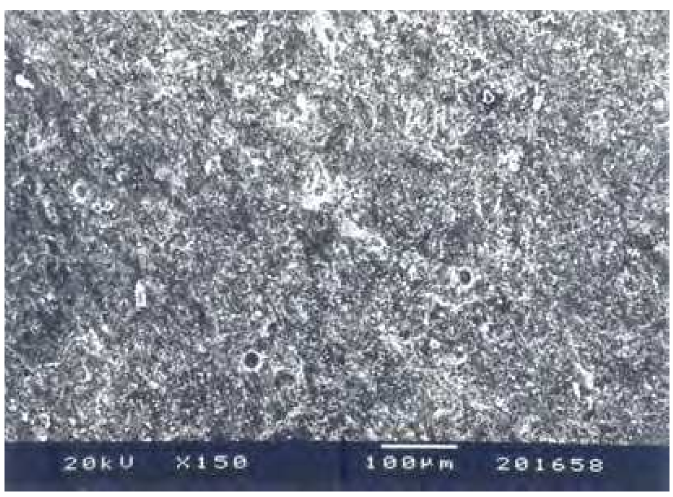


Fig. 19. The untreated surface showing intact glassy phase without any apparent crystals.

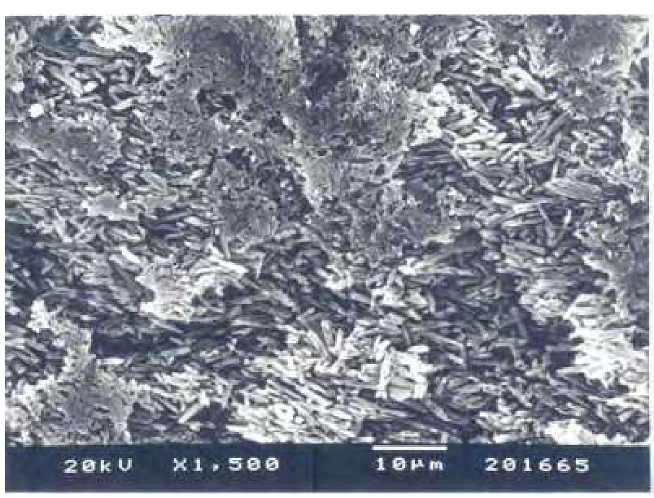


Fig. 20. 9.5% HF, 30 seconds. The surface has both apparent Li-disilicate crystals and glassy matrix. Glass matrix phase could not be completely removed if not applied homogenously and might lead to ill penetration of silane and the adhesive.

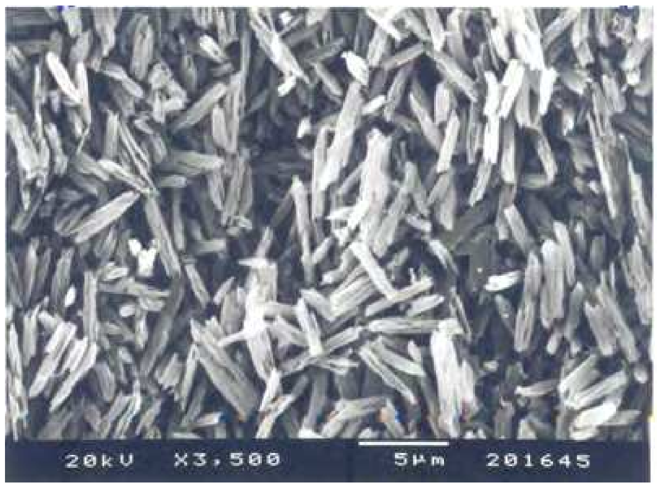


Fig. 21. 9.5% HF, 30 seconds. Visible Li-disilicate crystals. Completely removed glassy matrix. Appropriate etching pattern and surface for adhesive cementation (Gökçe et al., 2007).

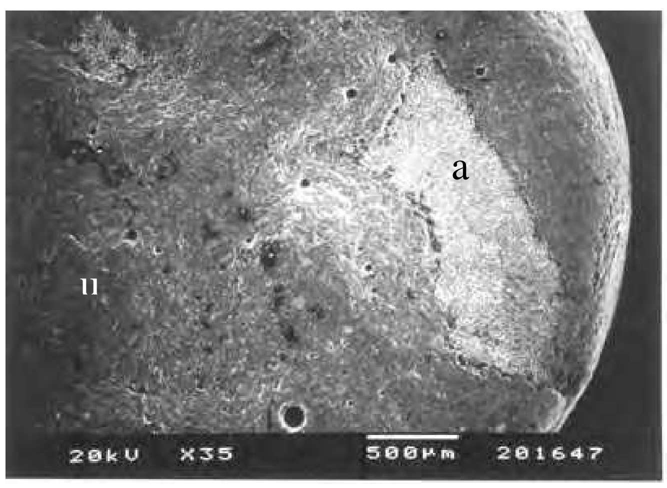


Fig. 22. Er:YAG laser, 300 mj, 10 Hz. Affected (a) and unaffected (u) areas of lased surface.

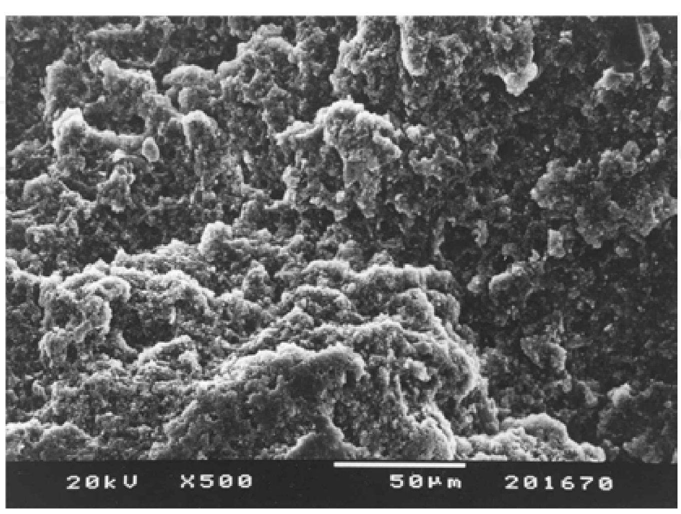


Fig. 23. Er:YAG laser, 300 mj, 10 Hz. Irregular Li-disilicate crystals in smaller sizes (Gökçe et al., 2007).

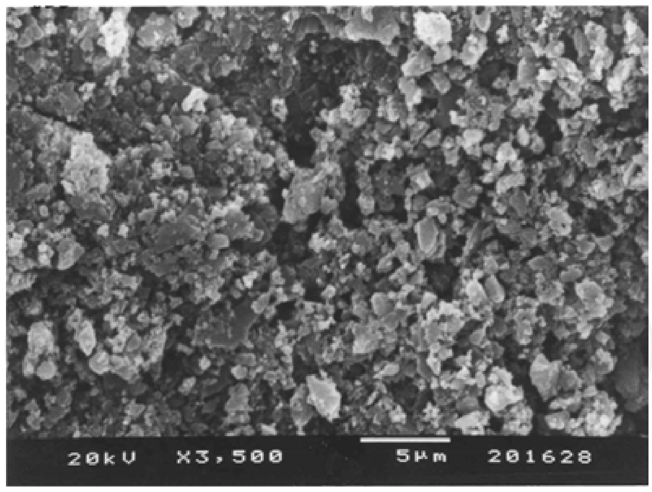


Fig. 24. Er:YAG laser, 600 mj, 10 Hz. Increased surface irregularities with severely affected and disassociated Li-disilicate crystals (Gökçe et al., 2007).

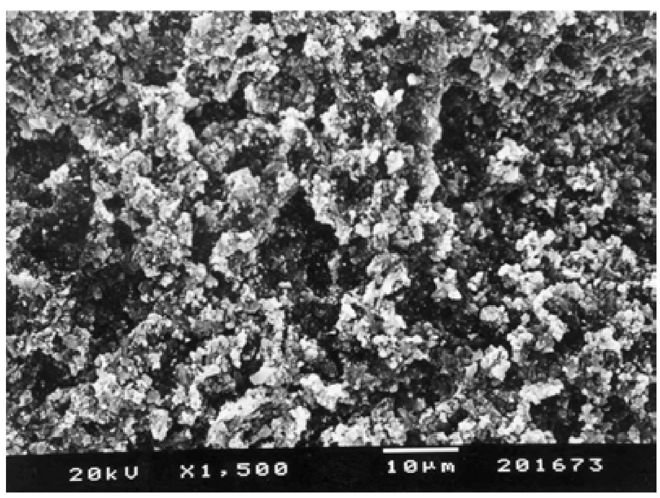


Fig. 25. Er:YAG laser, 900 mj, 10 Hz. Severely affected and disassociated Li-disilicate crystals (Gökçe et al., 2007).

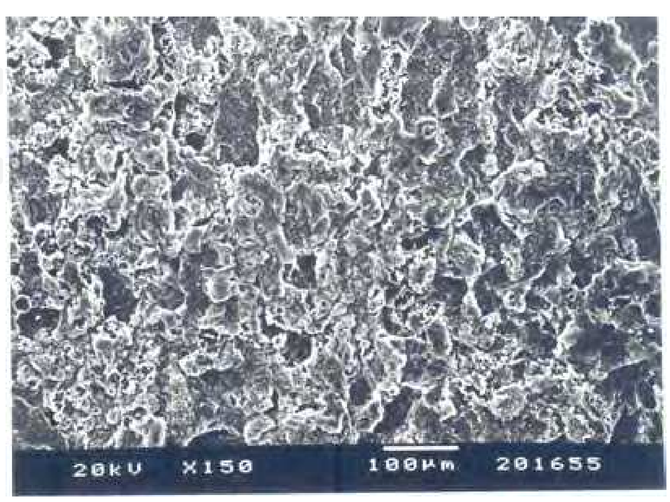


Fig. 26. Er:YAG laser, 1000 mj, 10 Hz. Melted and resolidified surface. This layer is poorly attached to the underlying intact phase.

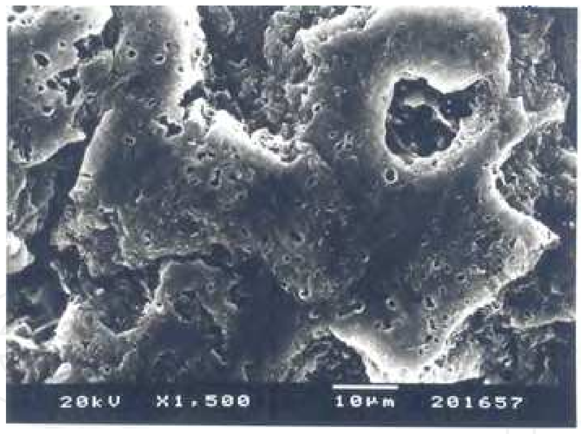


Fig. 27. Er:YAG laser, 1000 mj, 10 Hz. Higher magnification of the surface in Fig. 26.

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).

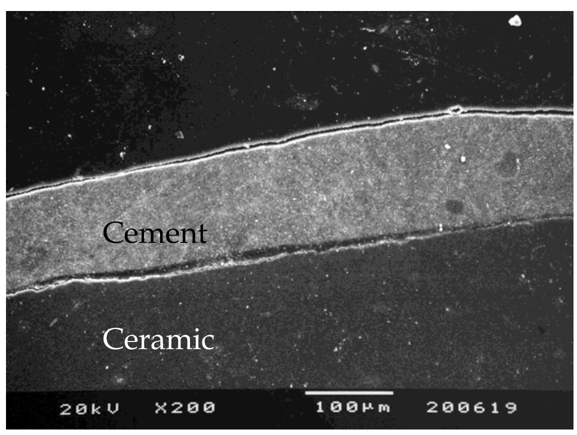


Fig. 28. Untreated ceramic surface. Adhesive failure inbetween the ceramic and the cement. No rough surfaces were noted on the ceramic (Gökçe et al., 2007).

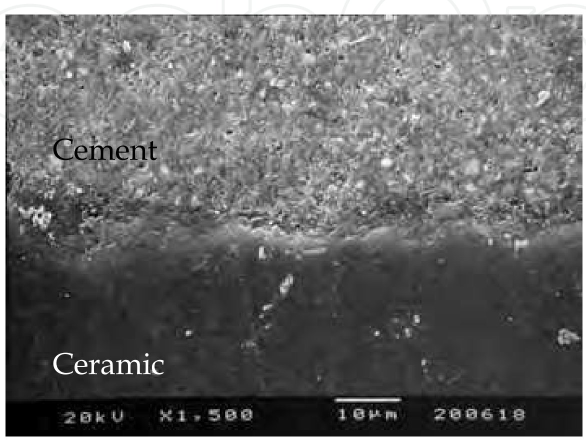


Fig. 29. 9.5% HF, 30 seconds. Good adhesion at the cement-ceramic interface with increased surface roughness. Mainly cohesive failures within the cement (Gökçe et al., 2007).

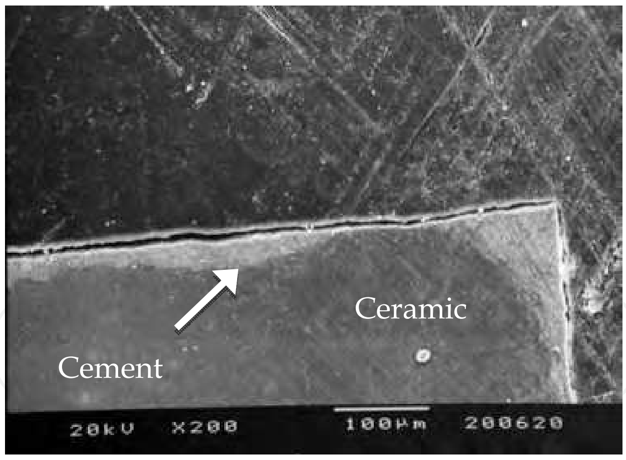


Fig. 30. Er:YAG laser, 300 mj, 10 Hz. No visible cement on the margins, while a cement remnant at the center of the specimen with adhesive+cohesive failures were observed (Gökçe et al., 2007).

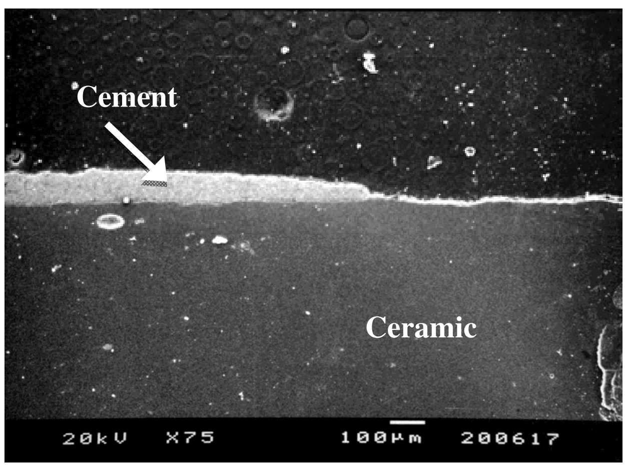


Fig. 31. Er:YAG laser, 600 mj, 10 Hz. Partially delaminated cement surfaces can be observed with adhesive failures (Gökçe et al., 2007).

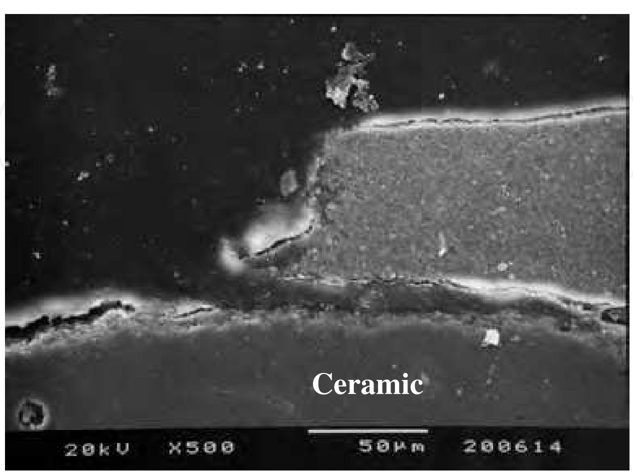


Fig. 32. Er:YAG laser, 900 mj, 10 Hz. Adhesive failure between cement and ceramic. Decreased irregularities and severe effects of laser on the ceramic surface (Gökçe et al., 2007).

3.2 Morphological analysis of sandblasted and Er: YAG laser-roughened alumina material

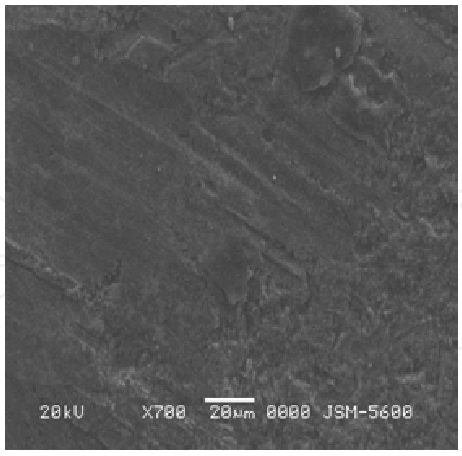


Fig. 33. Untreated In-Ceram Alumina (Şen, 2010).

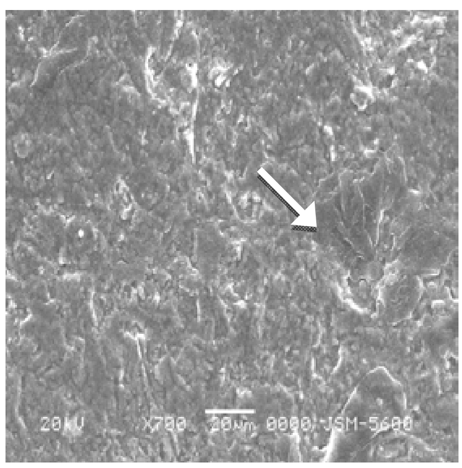


Fig. 34. In-Ceram Alumina. Airborne particle abrasion (110µm Al_2O_3). Affected and rougher surface compared to untreated surface with shallow pits (Şen, 2010).

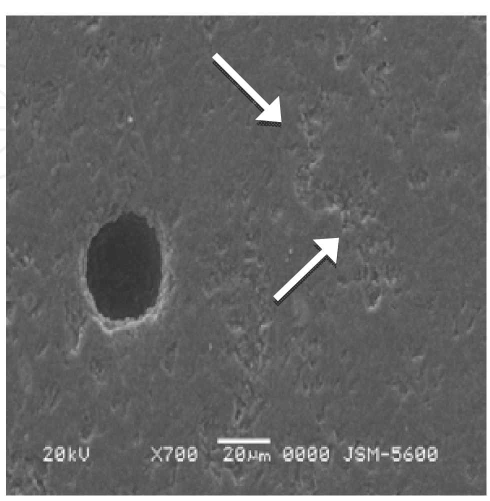


Fig. 35. In-Ceram Alumina. Er:YAG laser, 150 mj at 10 Hz with water cooling. Locally affected points on the surface due ton on homogenous application of the laser (Şen, 2010).

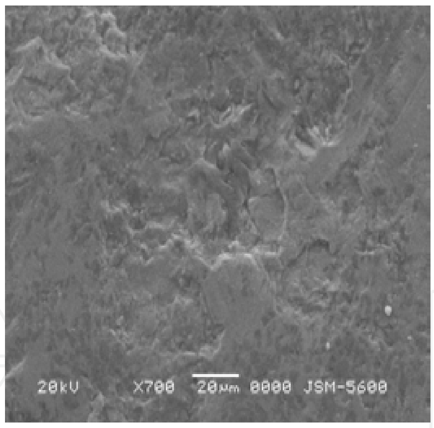


Fig. 36. In-Ceram Alumina. Er:YAG laser, 250 mj at 10 Hz with water cooling. Generalized effect of laser rougher surface compared to untreated and 150 mj laser applied surfaces (Şen, 2010).

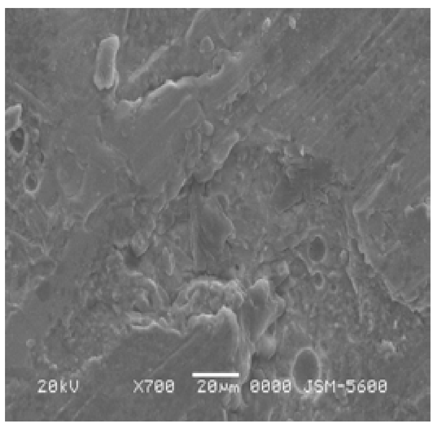


Fig. 37. In-Ceram Alumina. Er:YAG laser, 400 mj at 10 Hz with water cooling. Serrated and smoothened surface by resolidification of melted areas. This resolidified layer might be poorly attached to the underlying material (Şen, 2010).

3.3 Morphological analysis of sandblasted, silica coated and Er: YAG laser-roughened zirconia

3.3.1 SEM evaluation before shear bond strength testing

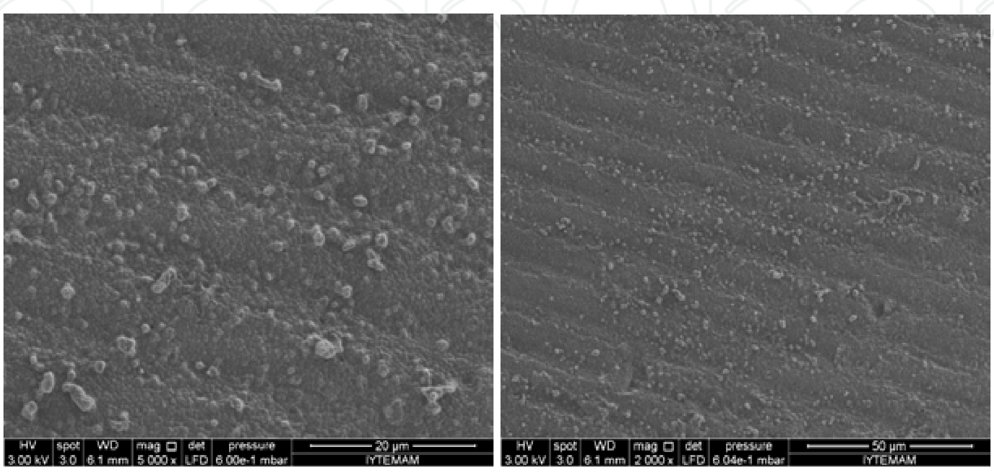


Fig. 38. Untreated zirconia. 2000x (left) and 5000x (right) magnifications (Erdem & Erdem, 2011).

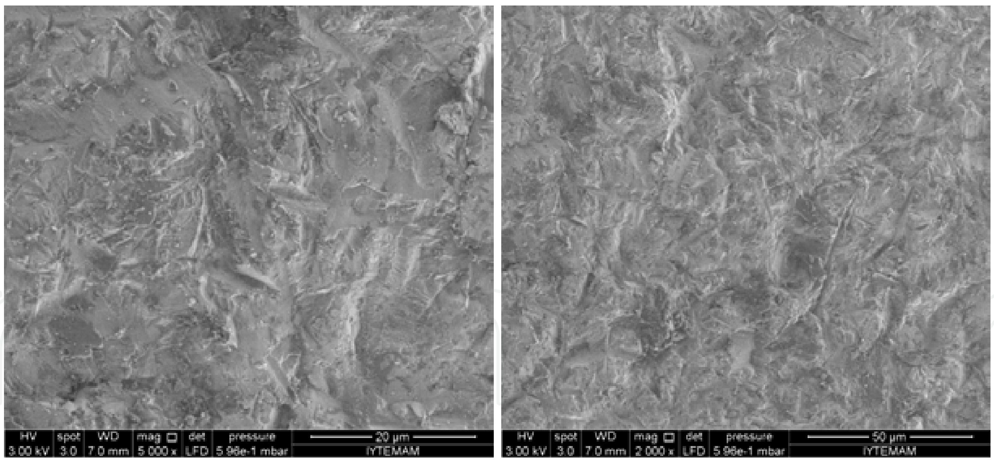


Fig. 39. Sandblasted (particle size 110 μm) zirconia. 2000x (left) and 5000x (right) magnifications. Increased roughness compared to untreated zirconia (Erdem & Erdem, 2011).

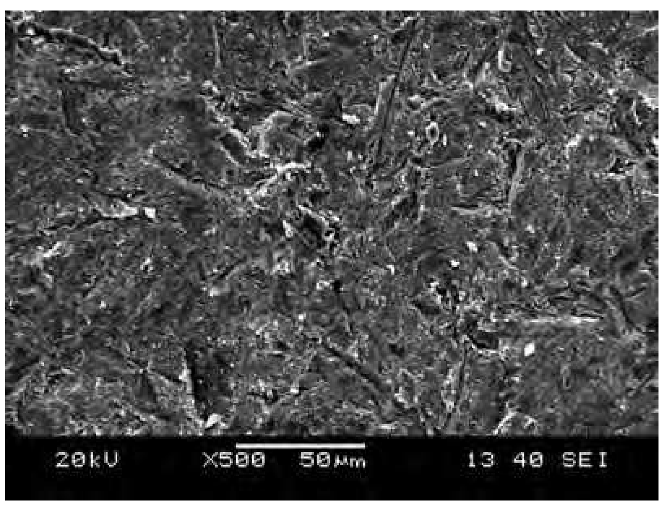


Fig. 40. Sandblasted (particle size 180 μm) zirconia. 500x magnification. Similar texture with the 110 μm air abraded surface.

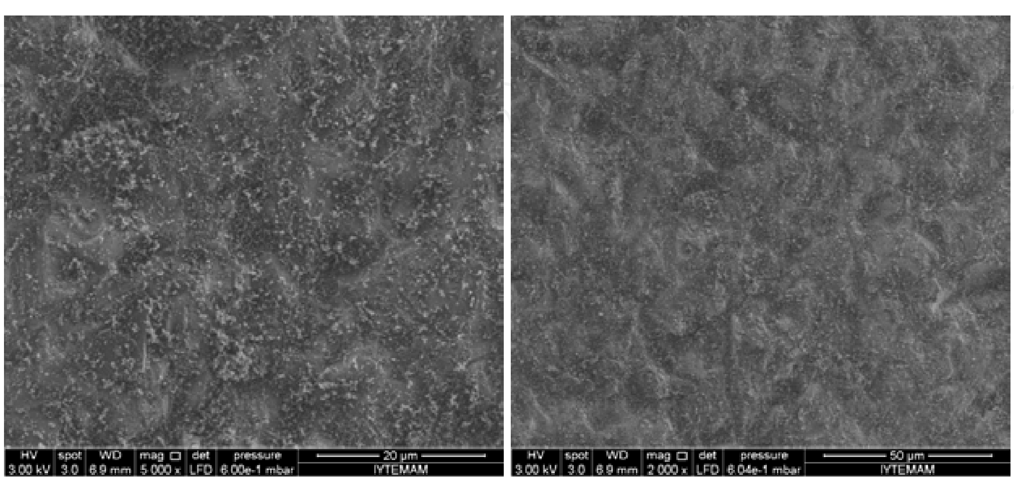


Fig. 41. Silica coated (Rocatec Pre110 μm and Rocatec Soft 30 μm) zirconia. 2000x (left) and 5000x (right) magnifications. Increased roughness similar to sandblasting and silica deposition on the surface can be observed (Erdem & Erdem, 2011).

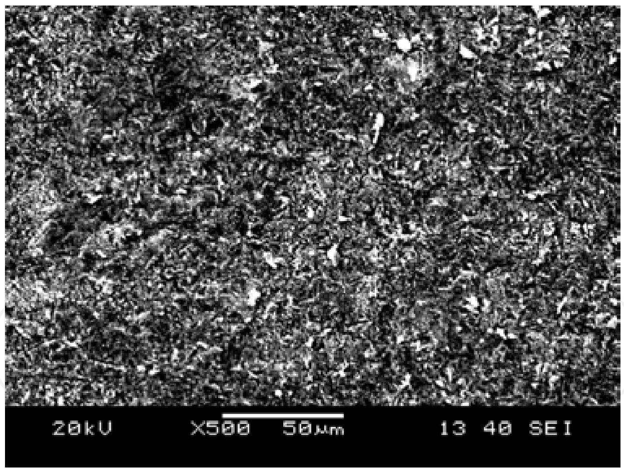


Fig. 42. Silica coated (Rocatec Pre110 µm and Rocatec Soft 30 µm) zirconia. 500x magnification. Increased roughness similar to particle abrasion with aluminum oxide (Şen, 2010).

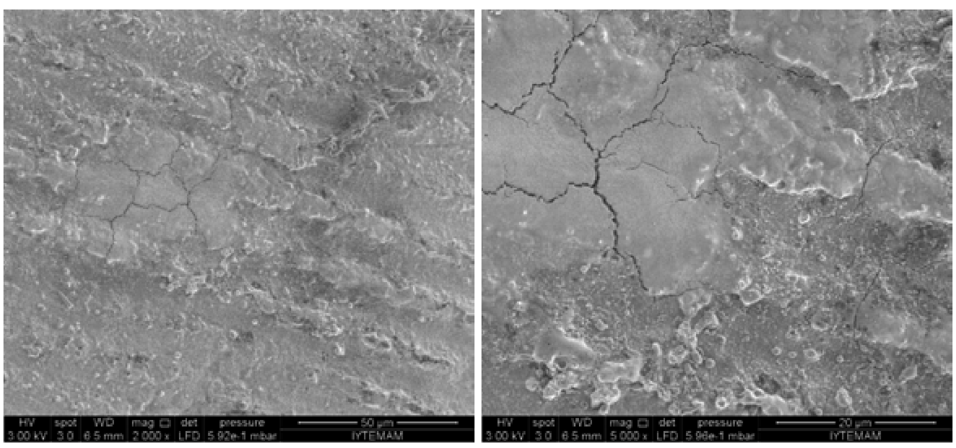


Fig. 43. Graphite coated and lased (200 mj, 10 Hz) zirconia. 2000x (left) and 5000x (right) magnifications. Rough and severely affected appearance with irregular surface (Şen, 2010) with micro cracks (Erdem & Erdem, 2011).

3.3.2 SEM evaluation after shear bond strength testing

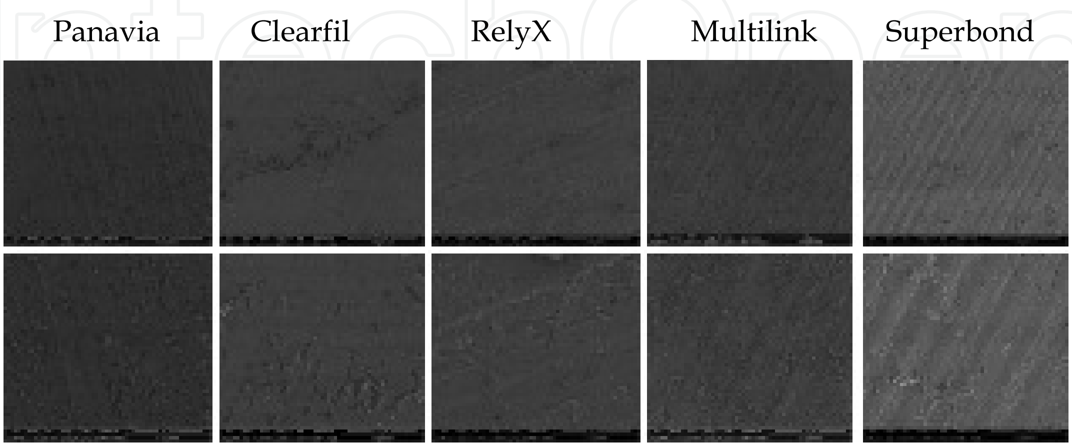


Fig. 44. Untreated zirconia. 2000x (first line) and 5000x (second line) magnifications. No cement retention was observed on untreated zirconia (Erdem & Erdem, 2011).

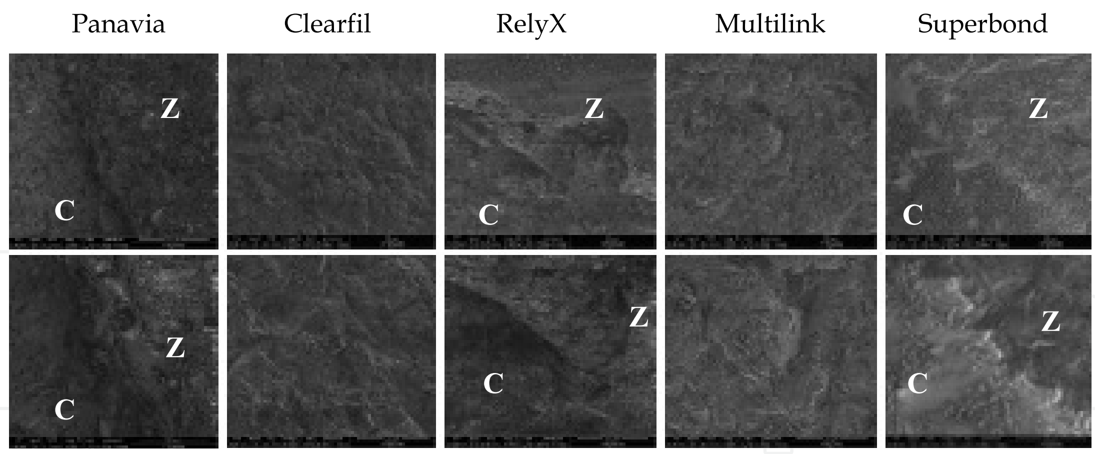


Fig. 45. Sandblasted (particle size 110 µm) zirconia. 2000x (first line) and 5000x (second line) magnifications. Two of the cements tested exhibited both adhesive and cohesive failures. (Z: Zirconia, C: Cement) (Erdem & Erdem, 2011).

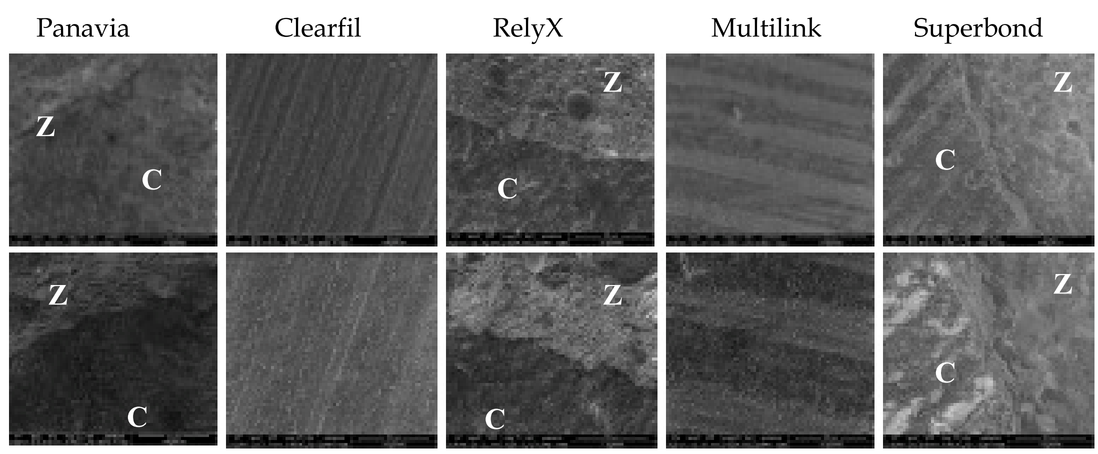


Fig. 46. Silica coated (Rocatec Pre110 µm and Rocatec Soft 30 µm) zirconia. 2000x (first line) and 5000x (second line) magnifications. Similar results with sandblasting was oserved after shear bond strength testing (Z: Zirconia, C: Cement) (Erdem & Erdem, 2011).

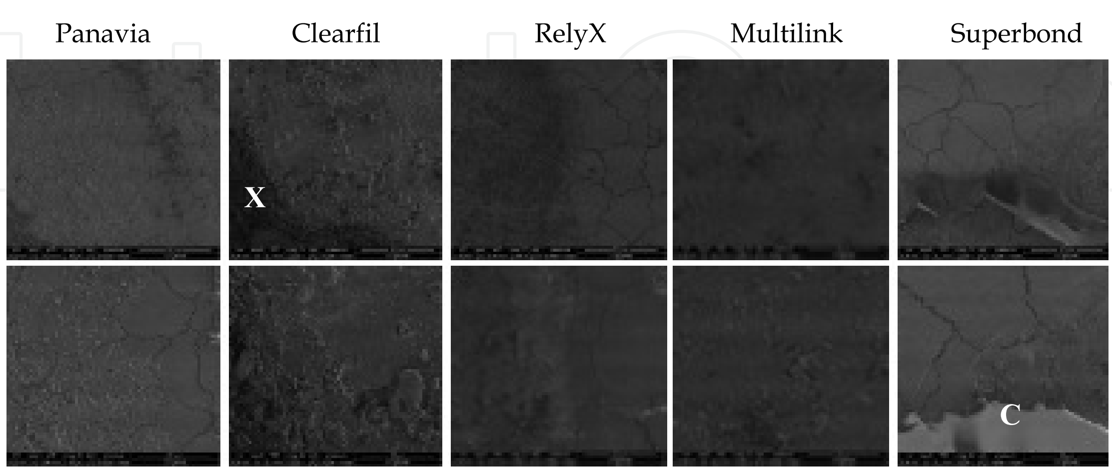


Fig. 47. Graphite coated and lased (200 mj, 10 Hz) zirconia. 2000 (first line) and 5000 (second line) magnifications. Adhesive failures observed in all cement groups. No cement retention on any of the groups. (X: severely affected area, C: Cement) (Erdem & Erdem, 2011).

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 CO_2 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.

5. References

Aboushelib, MN.; Kleverlaan, CJ. & Feilzer, AJ. (2007). Selective infiltration-etching technique for a strong and durable bond of resin cements to zirconia-based materials. *Journal of Prosthetic Dentistry*, Vol.98, No.5, pp. 379-388.

Akin, H.; Tugut, F.; Emine, A.G.; Guney, U. & Mutaf, B. (2011). Effect of Er:YAG laser application on the shear bond strength and microleakage between resin cements and Y-TZP ceramics. *Lasers in Medical Science,* Vol 21. [Epub ahead of print]

Akova, T.; Yoldas, O.; Toroglu, MS. & Uysal, H. (2005). Porcelain surface treatment by laser for bracket-porcelain bonding. *American Journal of Orthodontics & Dentofacial Orthopedics,* Vol.128, pp. 630–637.

Amaral, R.; Özcan, M.; Bottino, MA. & Valandro, LF. (2006). Microtensile bond strength of a resin cement to glass infiltrated zirconia-reinforced ceramic: the effect of surface conditioning. *Dental Materials,* Vol.22, pp. 283–290.

Aoki, A.; Ishikawa, I.; Yamada, T.; Otsuki, M.; Watanabe, H.; Tagami, J.; Ando, Y. & Yamamoto, H. (1998). Comparison between Er:YAG laser and conventional technique for root caries treatment in vitro. *Journal of Dental Research,* Vol.77, pp. 1404–1414.

Apel, C.; Meister, J.; Schmitt, N.; Gra˙ber, H.G. & Gutknecht, N. (2002). Calcium solubility of dental enamel fol- lowing sub-ablative Er:YAG and Er:YSGG laser irradiation in vitro. *Lasers in Surgical Medicine,* Vol.30, pp. 337–341.

Arima, M. & Matsumoto, K. (1993). Effects of ArF excimer laser irradiation on human enamel and dentin. *Lasers in Surgical Medicine,* Vol.13, pp. 97–105.

Ariyaratnam, MT.; Wilson MA. & Blinkhorn, AS. (1999). An analysis of surface roughness, surface morphology and composite/dentin bond strength of human dentin following the application of the Nd:YAG laser. *Dental Materials,* Vol.15, No.4, pp. 223-8.

Armengol, V.; Jean, A.; Rohanizadeh, R. & Hamel, H. (1999). Scanning electron microscopic analysis of diseased and healthy dental hard tissues after Er:YAG laser irradiation: in vitro study. *Journal of Endodontics*, Vol.25, No.8, pp. 543–546

Atsu, SS.; Kilicarslan, MA.; Kucukesmen, HC. & Aka, PS. (2006). Effect of zirconium-oxide ceramic surface treatments on the bond strength to adhesive resin. *Journal of Proshtetic Dentistry,* Vol.95, pp. 430–436.

Awliya, W.; Oden, A.; Yaman, P.; Dennison, JB. & Razzoog, ME. (1998). Shear bond strength of a resin cement to densely sintered high-purity alumina with various surface conditions. *Acta Odontologica Scandinavica,* Vol.56, pp. 9–13.

Ayad, MF.; Fahmy, NZ. & Rosenstiel, SF. (2008). Effect of surface treatment on roughness and bond strength of a heat-pressed ceramic. *Journal of Prosthetic Dentistry*, Vol.99, pp. 123–130

Bader, C. & Krejci, I. (2006). Marginal quality in enamel and dentin after preparation and finishing with an Er:YAG laser. *American Journal of Dentistry,* Vol.19, pp. 337–342.

Barkmeier, WW. & Cooley, RL. (1992). Laboratory evaluation of adhesive systems. *Operative Dentistry,* Supplementary 5, pp. 50-61

Blatz, MB.; Sadan, A. & Kern, M. (2003). Resin-ceramic bonding: a review of the literature. *Journal of Prosthetic Dentistry,* Vol.89, pp. 268–274.

Blatz, MB.; Sadan, A.; Martin, J. & Lang, B. (2004). In vitro evaluation of shear bond strengths of resin to densely-sintered high-purity zirconium-oxide ceramic after long-term storage and thermalcycling. *Journal of Prosthetic Dentistry,* Vol.91, pp. 356–362.

Boehm, R.; Rica, J.; Webster, J. & Janke, S. (1997). Thermal stress effects and surface cracking associated with laser use on human teeth. *Journal of Biomechanical Engineering,* Vol.99, pp. 189-194.

Borges, G.A.; Spohr, A.M.; Goes, M.F.; Correr Sobrinho, L. & Chan, J.D. (2003). Effect of etching and airborne parti- cle abrasion on the microstructure of different dental ceramics. *Prosthetic Dentistry,* Vol.89, pp. 479–487.

Bottino, MA.; Valandro, LF.; Scotti, R. & Buso, L. (2005). Effect of surface treatments on the resin bond to zirconium-based ceramic. *International Journal of Prosthodontics,* Vol.18, pp. 60–65.

Buonocore, MG. (1955). A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. *Journal of Dental Research,* Vol.34, No.6, pp. 849-853.

Burkes, EJ. Jr.; Hoke, J.; Gomes, E. & Wolbarsht, M. (1992). Wet versus dry enamel ablation by Er:YAG laser. *Journal of Prosthetic Dentistry,* Vol.67, No.6, pp. 847–851.

Cardoso, M.V.; Coutinho, E., Ermis, RB.; Poitevin, A.; Van Landuyt, K.; De Munck, J.; Carvalho, RC.; Lambrechts, P. & Van Meerbeek, B. (2008). Influence of Er,Cr:YSGG laser treatment on the microtensile bond strength of adhesives to dentin. *Journal of Adhesive Dentistry,* Vol.10, No.1, pp. 25–33.

Carvalho, AO.; Reis AF de Oliveira, MT.; de Freitas, PM.; Aranha, AC.; Eduardo, CD. & Giannini, M. (2011). Bond Strength of Adhesive Systems to Er,Cr:YSGG Laser-Irradiated Dentin. *Photomedicine and Laser Surgery,* Vol.16, (Epub ahead of print)

Cavalcanti, AN.; Foxton, RM.; Watson, TF.; Oliveira, MT.; Giannini, M. & Marchi, GM. (2009a). Bond strength of resin cements to a zirconia ceramic with different surface treatments. *Operative Dentistry,* Vol.34, No.3, pp. 280–287

Cavalcanti, AN.; Pilecki, P.; Foxton, RM.; Watson, TF.; Oliveira, MT.; Gianinni, M. & Marchi, GM. (2009b). Evaluation of the surface roughness and morphologic features of Y-TZP ceramics after different surface treatments. *Photomedicine and Laser Surgery,* Vol.27, No.3, pp. 473-479.

Ceballo, L.; Toledano, M.; Osorio, R.; Tay, FR. & Marshall, GW. (2002). Bonding to Er–YAG-laser-treated dentin. *Journal of Dental Research*, Vol.81, No.2, pp. 119–122

Cernavin, I. (1995). A comparison of the effects of Nd:YAG and Ho:YAG laser irradiation on dentine and enamel. *Australian Dental Journal,* Vol.40, pp. 79–84.

Cho, SA. & Jung, SK. (2003). A removal torque of the laser-treated titanium implants in rabbit tibia. *Biomaterials,* Vol.24, pp. 4859–4863

Clauss, C. (2000). All-ceramic restoration based on milled zirconia. *Zahn Mund Kieferheilkd Zentralbl,* Vol.18, pp. 436–442.

Convissar, RA. & Goldstein, EE. (2001). A combined carbon dioxide/ erbium laser for soft and hard tissue procedures. *Dentistry Today,* Vol.20, pp. 66–71.

Cooper, LF.; Myers, ML.; Nelson, DG. & Mowery, AS. (1988). Shear strength of composite bonded to laser pre-treated dentin. *J Prosthetic Dentistry,* Vol.60, pp. 45-49.

Corona, S.A.; de Souza, A.E.; Chinelatti, M.A.; Borsatto, M.C.; Pecora, J.D. & Palma-Dibb, R.G. (2007). Effect of energy and pulse repetition rate of Er: YAG laser on dentin ablation ability and morphological analysis of the laser-irradiated substrate. *Photomedicine and Laser Surgery,* Vol.25, pp. 26–33.

Curtis, A.R.; Wright, A.J. & Fleming, G.J. (2006). The influence of surface modification techniques on the performance of a Y-TZP dental ceramic. *Journal of Dentistry,* Vol.34, pp. 195–206.

Da Silveira, B.L.; Paglia, A.; Burnett, L.H.; Shinkai, R.S.; Eduardo, C.P. & Spohr, A.M. (2005). Micro-tensile bond strength between a resin cement and an aluminous ceramic treated with Nd:YAG laser, Rocatec System, or aluminum oxide sandblasting. *Photomedicine and Laser Surgery,* Vol.23, pp. 543–548.

De Munck, J.; Van Meerbeek, B.; Yudhira, R.; Lambrechts, P. & Vanherle, G. (2002). Microtensile bond strength of two Erbium:YAG-lased vs. bur-cut enamel and dentin. *European Journal of Oral* Sciences, Vol.110, pp. 322–329.

De Oliveira, M.T.; de Freitas, P.M.; de Paula Eduardo, C.; Ambrosano, G.M. & Giannini, M. (2007). Influence of di- amond sono-abrasion, air-abrasion and Er:YAG laser irra-diation on bonding of different adhesive systems to dentin. *European Journal of Oral* Sciences, Vol.1, pp. 158–166.

De Oyague, RC.; Monticelli, F.; Toledano, M.; Osorio, E.; Ferrari, M. & Osorio, R. (2009). Influence of surface treatments and resin cement selection on bonding to densely-sintered zirconium-oxide ceramic. *Dental Materials,* Vol.25, pp. 172–179

Della Bona, A.; Shen, C. & Anusavice, KJ. (2004). Work of adhesion of resin on treated lithia disilicate-based ceramic. *Dental Materials,* Vol.20, No.4, pp. 338-344.

Dunn, WJ.; Davis, JT. & Bush, AC. (2005). Shear bond strength and SEM evaluation of composite bonded to Er:YAG laser-prepared dentin and enamel. *Dental Materials*, Vol.21, No.7, pp. 616-624

Erdem A, Erdem A, (2011) Evaluation of bond strength of luting resins to a Y-TZP framework material processed with different surface treatments. PhD Thesis. Ege University School of Dentistry Department of Prosthodontics, Izmir, Turkey

Ersu, B.; Yuzugullu, B.; Ruya, Y.A. & Canay, S. (2009). Surface roughness and bond strengths of glass-infiltrated alumina- ceramics prepared using various surface treatments. *Journal of Dentistry,* Vol.37, pp. 848–856.

Esteves–Oliveira, M.; Zezell, DM.; Apel, C.; Turbino, ML.; Aranha, AC.;Eduardo Cde, P. & Gutknecht, N. (2007). Bond strength of self-etching primer to bur cut, Er,Cr:YSGG, and Er:YAG lased dental surfaces. *Photomedicine and Laser Surgery,* Vol.25, No.5, pp. 373–380.

Fabianelli, A.; Pollington, S.; Papacchini, F.; Goracci, C.; Cantoro, A.; Ferrari, M. & Van Noort, R. (2010). The effect of different surface treatments on bond strength between leucite reinforced feldspathic ceramic and composite resin. *Journal of Dentistry,* Vol.38, No.1, pp. 39–43.

Fradeani, M. & Redemagni, M. (2002). An 11-year clinical evaluation of leucite-reinforced glass-ceramic crowns: a retrospective study. *Quintessence International,* Vol.33, pp. 503–510.

Frentzen, M. & Koort, H.J. (1992). The effect of Er:YAG laser irradiation on enamel and dentin. *Journal of Dental Research,* Vol.71, pp. 571-577.

Frentzen, M.; Koort, H.J. & Thiensiri, I. (1992). Excimer laser in dentistry: future possibilities with advanced technology. *Quintessence International,* Vol.23, pp. 117–133.

Fried, D.; Featherstone, J.D.B.; Visuri, S.R.; Seka, W.D. & Walsh, J.T. (1996). The caries inhibition potential of Er:YAG and Er:YSGG laser radiation. *SPIE Proceedings,* 2672, pp. 73–78.

Fusayama, T.; Nakamura, M.; Kurosaki, N. & Iwaku, M. (1979). Non-pressure adhesion of a new adhesive restorative resin. *Journal of Dental Research,* Vol.58, pp. 1364–1370.

Gaggl, A.; Schultes, G.; Müller, WD. & Kärcher, H. (2000). Scanning electron microscopical analysis of laser-treated titanium implant surfaces–a comparative study. *Biomaterials,* Vol.21, pp. 1067–1073

Gökçe, B.; Özpınar, B.; Dündar, M.; Çömlekoglu, E.; Sen, BH. & Güngör, MA. (2007). "Bond Strengths of All Ceramics: Acid vs Laser Etching". *Operative Dentistry,* Vol.32, pp. 168-173.

Guazzato, M.; Albakry, M.; Ringer, SP. & Swain, MV. (2004). Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part II. Zirconia-based dental ceramics. *Dental Materials,* Vol.20, pp. 449–456.

Harashima, T.; Kinoshita, J. & Kimura, Y.; Brugnera, A.; Zanin, F.; Pecora JD. & Matsumoto, K. (2005). Morphological comparative study on ablation of dental hard tissues at cavity preparation by Er:YAG and Er,Cr:YSGG lasers. *Photomedicine and Laser Surgery,* Vol.23, No.1, pp. 52–55.

Haselton, DR.; Diaz-Arnold, AM. & Hillis, SL. (2000). Clinical assess- ment of high-strength all-ceramic crowns. *Journal of Prosthetic Dentistry,* Vol.83, pp. 396–401.

Hibst, R. & Keller, U. (1989). Experimental studies of the application of the Er:YAG laser on dental hard substances: I. Measurement of the ablation rate. *Laser in Surgery and Medicine,* Vol.9, No.4 , pp. 338– 344.

Hossain, M.; Nakamura, Y.; Yamada, Y.; Kimura, Y.; Nakamura, G. & Matsumoto, K. (1999). Ablation depths and morphological changes in human enamel and dentin after Er:YAG laser irradiation with or without water mist. *Journal of Clinical Laser in Medical Surgery,* Vol.17, pp. 105- 109.

Hossain, M.; Nakamura, Y.; Kimura, Y.; Yamada, Y.; Ito, M. & Matsumoto, K. (2000). Caries-preventive effect of Er:- YAG laser irradiation with or without water mist. *Journal of Clinical Laser in Medical Surgery,* Vol.18, pp. 61–65.

Hossain, M.; Nakamura, Y.; Yamada, Y.; Suzuki, N.; Mur- akami, Y. & Matsumoto, K. (2001). Analysis of surface roughness of enamel and dentin after Er,Cr:YSGG laser irradiation. *Journal of Clinical Laser in Medical Surgery,* Vol.19, pp. 297–303.

Hummel, M. & Kern, M. (2004). Durability of the resin bond strength to the alumina ceramic Procera. *Dental Materials,* Vol.20, No.5, pp. 498–508

Jacobsen, NL.; Mitchell, DL.; Johnson, DL. & Holt, RA. (1997). Lased and sandblasted denture base surface preparations affecting resilient liner bonding. *Journal of Prosthetic Dentistry*, Vol.78, No.2, pp. 153–158

Janda, R.; Roulet, JF.; Wulf, M. & Tiller, H-J. (2003). A new adhesive technology for all-ceramics. *Dental Materials,* Vol.19, No.6, pp. 567–573

Karakoca, S. & Yılmaz, H. (2009). Influence of surface treatments on surface roughness, phase transformation, and biaxial flexural strength of Y-TZP ceramics. *Journal of Biomedical Materials Research Part B: Applied Biomaterials,* Vol.91, No.2, pp. 930–937

Kayano, T.; Ochiai, S.; Kiyono, K.; Yamamato, H.; Nakajima, S. & Mochizuki, T. (1989). Effects of Er:YAG laser irradiation on human extracted teeth. *The Journal of the Stomatological Society, Japan,* Vol.56, No.2, pp. 381–392

Kataumi, M.; Nakajima, M.; Yamada, T. & Tagami, J. (1998). Tensile Bond strength and SEM evaluation of Er:YAG laser irradiated dentin using dentin adhesive. *Dental Materials Journal*, Vol.17, pp. 125–138

Keller, U. & Hibst, R. (1989). Experimental studies of the application of the Er:YAG laser on dental hard substances: II. Light microscopic and SEM investigations. *Lasers in Surgery and Medicine*, Vol.9, No.4, pp. 345–351

Kern, M. & Thompson, V.P. (1994). Sandblasting and silica coating of a glass-infiltrated alumina ceramic: volume loss, morphology, and changes in the surface composition. *Journal of Prosthetic Dentistry*, Vol.71, No.5, pp. 453–461

Kern, M. & Thompson, V.P. (1995). Bonding to glass infiltrated alumina ceramic: adhesive methods and their durability. *Journal of Prosthetic Dentistry*, Vol.73, No.3, pp. 240–249

Kern, M. & Wegner, SM. (1998). Bonding to zirconia ceramic: adhesion methods and their durability. *Dental Materials,* Vol.14, No.1, pp. 64–71

Kim, BK.; Bae, HE.; Shim, JS. & Lee, KW. (2005). The influence of ceramic surface treatments on the tensile bond strength of composite resin to all-ceramic coping materials. *Journal of Prosthetic Dentistry,* Vol.94, No.4, pp. 357–362

Kim, JT. & Cho, SA. (2009). The effects of laser etching on shear bond strength at the titanium ceramic interface. *Journal of Prosthetic Dentistry*, Vol.101, No.2, pp.101–106

Kramer, N.; Popp, S.; Sindel, J. & Frankenberger, R. (1996). Einfluss der Vorbehandlung von ompositinlays auf die Verbundfestigkeit. *Deutsch Zahnarztl Z*, Vol.51, pp. 598–601

Kumbuloglu, O.; Lassila, L.V.; User, A. & Vallittu, P.K. (2006). Bonding of resin composite luting cements to zirconium oxide by two air-particle abrasion methods. *Operative Dentistry*, Vol.31, No.2, pp. 248–255

Kutsch, VK. (1993). Lasers in dentistry: comparing wavelengths. *Journal of the American Dental Association,* Vol.124, No.2, pp.49-54

Lee, B.S.; Lin, P.Y.; Chen, M.H.; Hsieh, TT.; Lin, CP.; Lai, JY. & Lan, WH. (2007). Tensile bond strength of Er,Cr:YSGG laser-irradiated human dentin and analysis of dentin–resin interface. *Dental Materials,* Vol.23, No.5, pp.570–578.

Leinfelder, KF. (2001). Dentin adhesives for the twenty-first century. *The Dental Clinics of North America*, Vol.45, No.1, pp. 1-6

Li, R.; Ren, Y. & Han, J. (2000). Effects of pulsed Nd:YAG laser irradiation on shear bond strength of composite resin bonded to porcelain. *Hua Xi Kou Qiang Yi Xue Za Zhi,* Vol.18, No.6, pp. 377–379.

Li, Z.Z.; Code, J.E. & Van De Merwe, W.P. (1992). Er:YAG laser ablation of enamel and dentin of human teeth: Determination of ablation rates at various fluencies and pulse repetition rates. *Lasers in Surgery and Medicine,* Vol.12, No.6, pp. 625–630

Liberman, R.; Segal, TH.; Nordenberg, D. & Serebro, LI. (1984). Adhesion of composite materials to enamel: Comparison between the use of acids lasing as pretreatment. *Lasers in Surgery and Medicine*, Vol.4, No.4, pp. 232-237

Liu, J.F.; Liu, Y. & Stephen, H.C. (2006). Optimal Er:YAG laser energy for preventing enamel demineralization. Jo*urnal of Dentistry,* Vol.34, No.1, pp. 62–66

Malmström, HS.; McCormack, SM.; Fried, D. & Featherstone, JD. (2001). Effect of CO_2 laser on pulpal temperature and surface morphology: an in vitro study. *Journal of Dentistry,* Vol.29, No.8, pp. 521-529

Marshall Jr., GW.; Marshall, SJ.; Kinney, JH. & Balooch, M. (1997). The dentin substrate: structure and properties related to bonding. *Journal of Dental Research*, Vol.25. No.6, pp. 441-458

Matinlinna, JP. & Vallitu, PK. (2007). Bonding of resin composites to etchable ceramic surfaces – an insight review of the chemical aspects on surface conditioning. *Journal of Oral Rehabilitation,* Vol.34, No.8, pp. 622-630

McCormack, SM.; Fried, D.; Featherstone, JD.; Glena, RE. & Seka, W. (1995). Scanning electron microscope observations of CO2 laser effects on dental enamel. *Journal of Dental Research*, Vol.74, No.10, pp. 1702-1708

Moretto, SG.; Azambuja, N.Jr.; Arana–Chavez, V.E; Reis, AF.; Giannini M.; Eduardo C de P. & De Freitas, PM. (2010). Effects of ultramorphological changes on adhesion to lased dentin-Scanning electron microscopy and transmission electron microscopy analysis. *Microscopy Research Technique*, Vol.74, No.8, pp. 720–726

Nakabayashi, N.; Kojima, K. & Mashura E. (1982). The promotion of adhesion by resin infiltration of monomers into tooth structure. *Journal of Biomedical Materials Research*, Vol.16, pp. 265-273

Navarro, RS.; Gouw-Soares, S.; Cassoni, A.; Haypek, P.; Zezell, DM. & Eduardo, CP. (2010). The influence of erbium:yttrium-aluminum-garnet laser ablation with variable pulse width on morphology and microleakage of composite restorations. *Lasers in Medical Science*, Vol.25, No.6, pp. 881–889

Noda, M.; Okuda, Y.; Tsuruki, J.; Minesaki, Y.; Takenouchi, Y. & Ban, S. (2010). Surface damages of zirconia by Nd:YAG dental laser irradiation. *Dental Materials Journal,* Vol.29, No.5, pp. 536-541

Obata, A.; Tsumura, T.; Niwa, K.; Ashizawa, Y.; Deguchi, T. & Ito, M. (1999). Super pulse CO2 laser for bracket bonding and debonding. *European Journal of Orthodontics*, Vol.21, No.2, pp. 193–198

Oelgiesser, D.; Blasbalg, J. & Ben-Amar, A. (2003). Cavity preparation by Er-YAG laser on pulpal temperature rise. *American Journal of Dentistry*, Vol.16, No.2, pp. 96-98

Oliveira, MT.; Arrais, CA.; Aranha, AC.; Paula Eduardo, C.; Miyake, K.; Rueggeberg, FA. & Giannini, M. (2010). Micromorphology of resin–dentin interfaces using one-bottle etch & rinse and self-etching adhesive systems on laser- treated dentin surfaces: a confocal laser scanning microscope analysis. *Lasers in Surgery and Medicine,* Vol.42, No.7, pp. 662–670

Olsen, ME.; Bishara, SE.; Damon, P. & Jakopsen, JR. (1997a) Comparison of shear bond strength and surface structure between conventional acid etching and air abrasion of human enamel. *American Journal of Orthodontics and Dentofacial Orthopedics,* Vol.112, No.5, pp. 502-506

Olsen, ME.; Bishara, SE.; Damon, P. & Jakopsen, JR. (1997b). Evaluation of Scotchbond multipurpose and maleic acid as alternative methods of bonding orthodontic brackets. *American Journal of Orthodontics and Dentofacial Orthopedics,* Vol.111, No.5, pp. 498-501

Özcan, M.; Alkumru, HN. & Gemalmaz, D. (2001). The effect of surface treatment on the shear bond strength of luting cement to a glass-infiltrated alumina ceramic. *International Journal of Prosthodontics*, Vol.14, No.4, pp. 335–339

Özcan, M. (2002). The use of chairside silica coating for different dental applications: a clinical report. *The Journal of Prosthetic Dentistry*, Vol.87, No.5, pp. 469–472

Özcan M. (2003). Adhesion of resin composites to biomaterials in dentistry: an evaluation of surface conditioning methods. PhD Thesis, University of Groningen, Groningen, The Netherlands

Parker, S. (2004). The use of lasers in fixed prosthodontics. *Dental Clinics of North America,* Vol.48, No.4, pp. 971-998

Pashley, DH. (1992). The effects of acid etching on the pulpodentin complex. *Operative Dentistry*, Vol.17, pp. 229-242

Pashley, DH. & Carvalho, RM. (1997). Dentin permeability and dentin adhesion. *Journal of Dentistry*, Vol.25, pp. 355-372

Phark, JH.; Duarte S, Jr.; Blatz, M. & Sadan, A. (2009). An in vitro evaluation of the long-term resin bond to a new densely sintered high-purity zirconium-oxide ceramic surface. *The Journal of Prosthetic Dentistry,* Vol.101, No.1, pp. 29–38

Ramos, A.C.; Esteves-Oliveira, M., Arana-Chavez, V.E. & de Paula Eduardo, C. (2010). Adhesives bonded to erbium: yttrium–aluminum–garnet laser-irradiated dentin: transmission electron microscopy, scanning electron microscopy and tensile bond strength analyses. *Lasers in Medicine and Science*, Vol.25, No.2, pp. 181–189

Reynold, IR. (1975). A review of direct bonding. *British Journal of Orthodontics*, Vol.2, pp. 171-180

Roberts-Harry, DP. (1992). Laser etching of teeth for orthodontic bracket placement: A preliminary clinical study. *Lasers in Surgery and Medicine*, Vol.12, No.5, pp. 467-470

Sakakibara, Y.; Ishimaru, K. & Takamizu, M. (1998). A study on bond strength to dentin irradiated be Erbium:YAG laser. *The Japanese Journal of Conservative Dentistry*, Vol.41, pp. 207-219

Sasaki, LH.; Lobo, PD.; Moriyama, Y.; Watanabe, IS.; Villaverde, AB.; Tanaka, CS.; Moriyama, EH. & Brugnera A, Jr. (2008). Tensile bond strength and SEM analysis of enamel etched with Er:YAG laser and phosphoric acid: a comparative study in vitro. *Brazilian Dental Journal*, Vol.19, No.1, pp. 57-61

Sato, H.; Yamada, K.; Pezzotti, G.; Nawa, M. & Ban, S. (2008). Mechanical properties of dental zirconia ceramics changed with sandblasting and heat treatment. *Dental Materials Journal,* Vol.27, No.3, pp. 408–414

Schein, MT.; Bocangel, JS.; Nogueira, GE. & Schein, PA. (2003). SEM evaluation of the interaction pattern between dentin and resin after cavity preparation using ER:YAG laser. *Journal of Dentistry,* Vol.31, No.2, pp. 127-135

Schmage, P.; Nergiz, I.; Herrmann, W. & Özcan, M. (2003). Influence of various surface-conditioning methods on the bond strength of metal brackets to ceramic surfaces. *American Journal of Orthodontic Dentofacial Orthopedic,* Vol.123, No.5, pp. 540-546

Sen, D.; Poyrazoglu, E.; Tuncelli, B. & Goller, G. (2000). Shear bond strength of resin luting cement to glass-infiltrated porous aluminum oxide cores. *The Journal of Prosthetic Dentistry*, Vol.83, No.2, pp. 210–215

Şen S & Ceylan G. (2010) The Effects of Different Surface Treatments on the Bond Strength of Zirconium-Oxide Ceramic and Adhesive Resin. PhD Thesis. Ondokuz Mayıs University, School of Dentistry Department of Prosthodontics, Samsun, Turkey.

Sharpe, AN. (1967). Influence of the crystal orientation in human enamel on its reactivity to acid as shown by high resolution microradiography. *Archieves of Oral Biology*, Vol.12, No.5, pp. 583-591

Sindel, J.; Gehrlicher, S. & Petschel, A. (1996). Untersuchungen zur Haftung von Kompositan VMK-Kerakim. *Deutsch Zahnarztl Z.*, Vol.51, pp. 712–716

Spohr, AM.; Borges, GA.; Júnior, LH.; Mota, EG. & Oshima, HM. (2008). Surface modification of In-Ceram Zirconia ceramic by Nd:YAG laser, Rocatec system, or aluminum oxide sandblasting and its bond strength to a resin cement. *Photomedicine and Laser Surgery,* Vol.26, No.3, pp. 203-208

Stern, RH.; Vahl, J. & Sognnaes, RF. (1972). Lased enamel: ultrastructural observations of pulsed carbon dioxide laser effects. *Journal of Dental Research*, Vol.51, No.2, pp. 455-460

Stu̇binger, S.; Homann, F.; Etter, C.; Miskiewicz, M.; Wieland, M. & Sader, R. (2008). Effect of Er:YAG, CO2 and diode laser irradiation on surface properties of zirconia endosseous dental implants. *Lasers in Surgery and Medicine*, Vol.40, No.3, pp. 223-228

Subaşı, MG. & Inan, O. (2011). Evaluation of the topographical surface changes and roughness of zirconia after different surface treatments. *Lasers in Medical Science*, July 24. [Epub ahead of print]

Tachibana, A.; Marques, MM.; Soler, JM. & Matos, AB. (2008). Erbium, chromium:yttrium scandium gallium garnet laser for caries removal: influence on bonding of a self-etching adhesive system. *Lasers in Medical Science*, Vol.23, pp. 435–441

Toksavul, S. & Toman, M. (2007). A short-term clinical evaluation of IPS Empress 2 crowns. *The International Journal of Prosthodontics*, Vol.20, No.2, pp. 168–172

Trajtenberg, CP.; Pereira, PN. & Powers JM. (2004). Resin bond strength and micromorphology of human teeth prepared with an Erbium:YAG laser. *American Journal of Dentistry,* Vol.17, No.5, pp. 331-336

Ural, Ç.; Külünk, T.; Külünk, Ş. & Kurt, M. (2010). The effect of laser treatment on bonding between zirconia ceramic surface and resin cement. *Acta Odontologica Scandinavica*, Vol.68, No.6, pp. 354-359

Van Meerbeek, B.; De Munck, J. & Yoshida, Y. (2003). Buonocore memorial lecture. Adhesion to enamel and dentin: current status and future challenges. *Operative Dentistry*, Vol.28, pp. 215–235

Van Noort, R. (2002a). Dental Ceramics, In: *An introduction to dental materials*, Van Noort R, (Ed.), 231–246, Elsevier Science, Hong Kong

Van Noort, R. (2002b). Principles of adhesion. In: *An introduction to dental materials*, Van Noort R, (Ed.), 68-78, Elsevier Science, Hong Kong

Visuri, SR.; Gilbert, JL.; Wright, DD.; Wigdor, HA. & Walsh, JT. Jr. (1996a). Shear strength of composite bonded to Er:YAG laser-prepared dentin. *Journal of Dental Research*, Vol.75, pp. 599–605

Visuri, SR.; Walsh, JT.; & Wigdor, HA. (1996b). Erbium laser ablation of dental hard tissue: Effect of water cooling. *Lasers in Surgery and Medicine*, Vol.18, No.3, pp. 294–300

Walsh, LJ. (1994). Clinical evaluation of dental hard tissue applications of carbon dioxide lasers. *Journal of Clinical Laser Medicine & Surgery*, Vol.12, No.1, pp. 11-15

Watanabe, I.; McBride, M.; Newton, P. & Kurtz, KS. (2009). Laser surface treatment to improve mechanical properties of cast titanium. *Dental Materials*, Vol.25, No.5, pp. 629–633

White, JM.; Goodis, HE.; Setcos, JC.; Eakle S.; Hulscher BE. & Rose CL. (1993). Effects of pulsed Nd:YAG laser energy on human teeth: a three-year follow- up study. *Journal of American Dental Association*, Vol.124, No.7, pp. 45–51

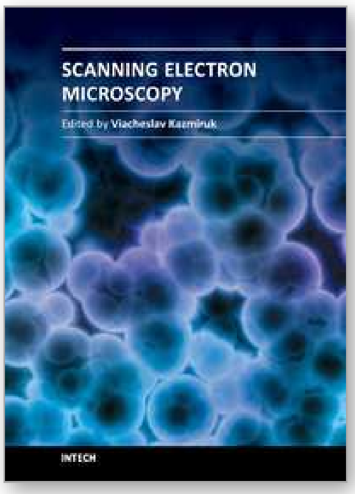
Wigdor, H.; Abt, E.; Ashrafi, S. & Walsh JT. Jr. (1993). The effect of lasers on dental hard tissues. *Journal of American Dental Association,* Vol.124, No.2, pp. 65–70

Wilder-Smith, P.; Lin, S.; Nguyen, A.; Liaw LH.; Arrastia AM.; Lee JP. & Berns MW. (1997). Morphological effects of ArF excimer laser irradiation on enamel and dentin. *Lasers in Surgery and Medicine*, Vol.20, No.2, pp. 142–148

Zachrisson, BU. & Buyukyılmaz, T. (1993). Recent advances in bonding to gold, amalgam and porcelain. *Journal of Clinical Orthodontics*, Vol.27, pp. 661-675

Zhang, Y.; Lawn, BR.; Rekow, ED. & Thompson, VP. (2004). Effect of sandblasting on the long-term performance of dental ceramics. *Journal of Biomedical Materials Research. Part B Applied Biomaterials*, Vol.71, No.2, pp. 381–386

Zhang, Y.; Lawn, BR.; Malament, KA.; Van Thompson, P. & Rekow, ED. (2006). Damage accumulation and fatigue life of particle-abraded ceramics. *The International Journal of Prosthodontics*, Vol.19, No.5, pp. 442–448



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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.