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Er:YAG Laser Debonding of Porcelain Veneers

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Background and Objectives: The removal of porcelain veneers using Er:YAG lasers has not been previously described in the scientific literature. This study was designed to systematically investigate the efficacy of an Er:YAG laser on veneer debonding, possibly without damage to the underlying tooth, and preservation of the veneer integrity.

Study Design/Materials and Methods: The Fourier Transform Infrared Spectroscopy was used on 10 flat veneer samples (IPS Empress Esthetic, e.max Press HT) to assess which infrared laser wavelengths transmits through a veneer. Additionally, Fourier Transform Infrared (FTIR) spectra for a bonding cement (RelyX) were obtained. Consequently, Er:YAG laser energy transmission (wavelength 2,940 nm, 10 Hz repetition rate, pulse duration 100 μseconds at 133 mJ/pulse) through different veneer thicknesses was measured. Twenty-four veneers were bonded to freshly extracted and prepared incisors. The energy necessary for debonding was determined and then the veneers were debonded with the laser. Time needed for total debonding was measured and possible damage to the underlying tooth structure was assessed by light microscopy.

Results: While the veneer materials did not show any characteristic water absorption bands in the FTIR, the bonding cement showed a broad H_2O/OH absorption band. The veneers transmitted between 11.5% and 43.7% of the incident Er:YAG energy with Emax transmitting twice the energy as EE at comparable thicknesses. Initial signs of cement ablation occurred at 1.8–4.0 J/cm^2 with the fiber tip positioned at a distance of 3–6 mm from the veneer surface and 133 mJ output energy. All 24 bonded veneers were completely removed with an average removal time of 113 ± 76 seconds. Underlying tooth structure was not damaged. The debonding mainly occurred at the cement/veneer interface. None of the Emax veneers fractured during debonding, while 36% of the EE did.

Conclusion: Er:YAG laser irradiation effectively debonds porcelain veneers while preserving tooth structure. Maintaining veneer integrity possibly depends on the flexure strength of the veneer porcelain. Lasers Surg. Med. 43:965–974, 2011. © 2011 Wiley Periodicals, Inc.

Key words: Er:YAG laser; veneer debonding; porcelain veneers; FTIR; energy transmission; veneer flexure strength

INTRODUCTION

Dental veneers are very thin porcelain facings placed on front teeth to improve esthetics. They are glued on with a light-curing or self-curing resin after the tooth has undergone minimal invasive preparation, which is typically limited to enamel—the outer layer of a tooth. Veneer removal is generally performed with a rotary instrument. Using this method the veneer removal is complete, but is relatively time consuming and this technique is not ideal as the underlying tooth structure may be damaged. Since the most common reason for removal of a veneer is caries around its margins requiring an extended tooth preparation, it is obviously acceptable that the removal of the veneer is accompanied by the destruction of the veneer. Little research has been done in alternative veneer removal techniques. With the introduction of pulsed lasers into dentistry, there may be a beneficial application of such lasers for removing veneers. To the best of our knowledge, this is the first scientific publication studying laser debonding of porcelain veneers.

Short-pulsed laser ablation may be a promising method for the debonding of veneers while avoiding overheating of the pulp. If the cement is rapidly ablated, then heat conduction by the slow process of thermal softening [1–3] can be avoided [4]. The Er:YAG laser is safe for ablation of dental hard tissues [5–8] as well as composite resin [9–11]. Rising pulse repetition rate during composite removal results in a linear increase in the pulpal temperature, but still does not cause a temperature increase above the limit considered safe for the pulp vitality [10].

The objective of this laboratory study was to determine the efficacy of laser debonding of dental porcelain veneers from extracted teeth. The hypotheses were that using an Er:YAG laser: (1) allows for complete debonding of porcelain veneers from extracted teeth, (2) without damage to or removal of underlying healthy tooth structure, and (3) without destroying the veneers, in the rare occasion that

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a mishap occurred at the veneer bonding appointment and a veneer had been inaccurately placed.

MATERIALS AND METHODS

Porcelain Veneers

The porcelain veneer materials used in this study were IPS Empress Esthetic (EE) (leucite glass-ceramic) and IPS e.max Press HT (Emax) (lithium disilicate glass-ceramic, high translucency; Ivoclar, Vivadent, Switzerland). The veneers were produced in a dental laboratory (Dental Masters, Santa Rosa, CA) according to the manufacturer's instructions.

Standard Flat Veneers

A set of five standardized veneers from each material with flat surfaces (5 mm × 5 mm, average thickness 1.23 ± 0.06 mm; EE 1.26 ± 0.04 mm, Emax 1.21 ± 0.07 mm [mean ± SD]; Mitutoyo micrometer, model # IDC-112E, Mitutoyo America, Aurora, IL) was produced to assess the absorption characteristics of each veneer material by Fourier Transform Infrared (FTIR) spectroscopy (Nicolet, Thermo Fisher Scientific FT-IR Spectrometer, Waltham, MA). In addition, these veneers were used to assess energy transmission and consequent ablation of cement through the veneers (see below).

Regular Veneers

Twenty-four freshly extracted anterior incisor teeth were gamma irradiated and stored in thymol solution (0.1%) until use. Veneer preparations were made and restricted to the enamel (diamond cylindrical burr 5856.31.021, Brassler, Savannah, GA). After impressions, the prepared teeth were stored in physiological saline solution. Impressions were made with regular body polyvinylsiloxane (Reprosil, Dentsply Caulk, Milford, DE), and sent to the laboratory for the fabrication of the veneers (11 EE veneers, 13 Emax veneers).

After delivery from the laboratory the thickness of each veneer was measured at three locations – at the thickest area at the incisal edge, in the middle third, and the thinnest area in the cervical third of the veneer. All veneer thickness measurements were repeated three times per location and averaged (Mitutoyo micrometer, model # IDC-112E, Mitutoyo America).

Three tooth formed veneers of each veneer material were also used to measure the energy transmission for calculation of the transmission loss through the veneer at the incisal, middle, and cervical areas.

Veneer Cement

To achieve a basic understanding about absorption characteristics as well as ablation thresholds of typical dental veneer cements, a series of cement samples was prepared. The veneer cement tested was 3M ESPE RelyX for Veneers shade A1 (3M ESPE, St. Paul, MN), a light-cure only resin cement (bisGMA and TEGDMA polymer with zirconia/silica and fumed silica fillers) (cement samples 3 mm diameter, 1.5–2.5 mm thickness; light curing 20 seconds on both sides).

To determine the absorption characteristics of the veneer cement in the infrared spectral range, three cement samples were used for the FTIR spectroscopy.

Three other cement samples were used to establish the ablation thresholds of the veneer cement. The determination of the cement ablation threshold was done by visual inspection using magnifying glasses (2× magnification) and a light microscope (Olympus Microscope BX50; 2×, 5×, 10×, 20×, and 50× magnification; imaging micropublisher 3.3, Canada, program image pro). First visible changes of the cement surface (small ablation crater with fume generation) were registered and the corresponding laser energy was noted.

For verification of energy transmission through the veneer and consecutive ablation of cement, the standard flat veneer samples were placed on top of cement samples. The distance of the irradiation fiber tip to the veneer surface at ablation onset was measured.

Laser Settings

The laser utilized in this study was an Er:YAG laser (LiteTouch by Syneron; wavelength 2,940 nm, 10 Hz repetition rate, pulse duration 100 μseconds (pulse duration measured with a thermoelectrically cooled HgCdZnTe [HCZT] detector; BSA Technology Model PCI-L-2TE-12, Torrance, CA) at 133 mJ/pulse; straight sapphire tip 1,100 μm diameter, different distances to target (see below), with air spray; Syneron, Yokneam, Israel). Before and after each step of an experiment, the laser energy output at the end of the fiber tip was verified with an energy meter (Energymax 400, Molectron Detector, Inc., Portland, OR).

For the energy transmission measurements through the regular veneers the sapphire tip was used in direct contact to the veneer. Energy transmission through veneer material samples was determined using the Er:YAG laser at five different set energies delivered by the laser system (133, 217, 316, 400, and 503 mJ per pulse) with a pulse repetition rate of 10 Hz. All transmission measurements were repeated three times at a minimum, using three EE veneers and three Emax veneers.

During the experiments to remove the bonded veneers the energy was set to the lowest possible energy setting delivered by the system (133 mJ). Also, the fiber was kept in a distance to achieve the lowest energy needed to ablate the cement through the veneers.

Laser Debonding of Veneers

After bonding to the teeth from the 11 EE and the 13 Emax veneers, a subset of 3 bonded veneers of each material group was immersed in saline solution. It was kept there for 5 days before laser debonding to simulate the effect of having initial contact with saliva. The remaining 8 EE and 10 Emax veneers (bonded to the teeth) were kept dry after bonding to simulate freshly placed/misplaced veneers.

Immediately after bonding and 3 days after storing in saline solution, respectively, the EE veneers and the Emax veneers were removed with the Er:YAG laser at the lowest energy settings possible with 133 mJ/pulse, 10 Hz, 3–6 mm distance of the fiber tip to the veneer applying air spray. For the removal a simple irradiation pattern was used. First, all margins of the veneer were irradiated avoiding the thinnest cervical areas. This was followed by a horizontal parallel "laser-painting" of the veneer surface, starting from the incisal edge down to the cervical margins.

The time for complete veneer removal was noted as was whether or not the veneer was removed as whole or in pieces.

RESULTS

Porcelain Veneers

Fourier transform infrared spectroscopy (FTIR) of porcelain veneers. The FTIR spectra of the five standardized flat Empress Esthetic veneer samples revealed a strong peak most likely related to silica (wavenumber position at around 1,100 wavenumber). The FTIR spectra also determined that the EE veneers do not show any characteristic H_2O/OH absorption bands (wavenumber 3,750–3,640, and 3,600–3,400, respectively) (Fig. 1). The FTIR spectra from five standardized flat e.max HT Press veneers demonstrated the same characteristic absorption peaks (strong silica peak could overlap a phosphate peak since veneer contains small amounts of phosphate) and no water absorption bands (Fig. 2).

Thus, with no distinct absorption around the Er:YAG laser emission wavelength of 2,940 nm (wavenumber 3,400) the FTIR results predicted that the Er:YAG laser irradiation will not be strongly absorbed by the tested porcelain veneer materials but could be transmitted through the veneer.

Energy transmission through veneers. To calculate energy loss during transmission of the Er:YAG laser light through the porcelain veneers, laser irradiation was performed perpendicular to the veneer surface with the laser tip in contact and the energy was measured on the opposing side behind the veneer. Three regular veneers of each material were used to measure the energy transmission.

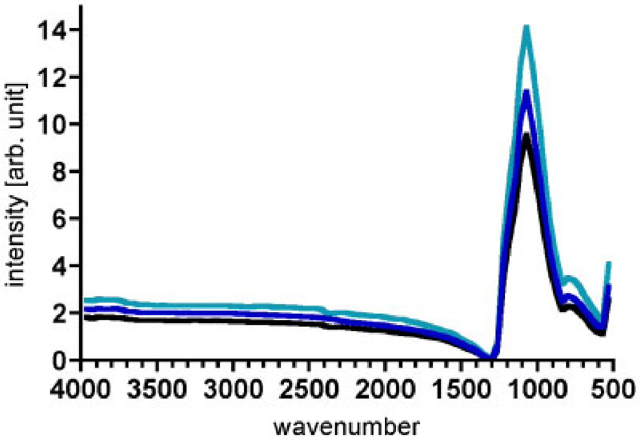

Fig. 1. FTIR spectra of three standardized veneer samples IPS Empress Esthetic, exhibiting a strong silica peak (at around 1,100 wavenumber); no water absorption band detected (spectra from three samples overlaid).

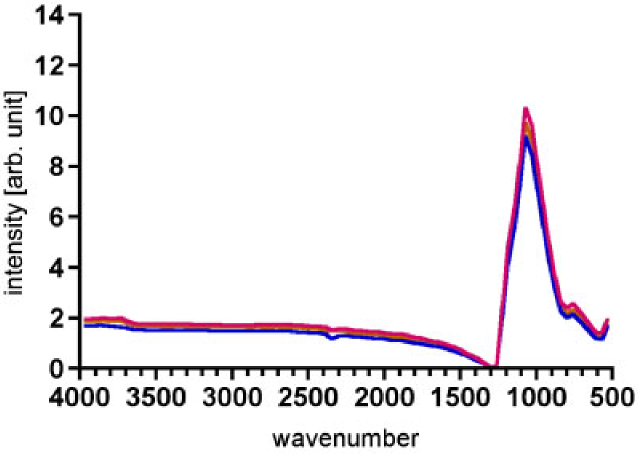

Fig. 2. FTIR spectra of three standardized IPS e.max Press HT veneer samples, exhibiting a strong silica peak (at around 1,100 wavenumber, the strong silica peak could overlap a phosphate peak since veneer contains small amounts of phosphate); no water absorption band detected (spectra from three samples overlaid).

The laser was set to the five different available output energies of 133, 220, 310, 398, and 486 mJ per, 10 Hz repetition rate. Figure 3 for EE and Figure 4 for Emax, respectively, show the average energy transmitted for the different laser energies (mean ± SD) in relation to the veneer thickness; a liner regression curve fit has been calculated. Table 1 for EE veneer and Table 2 for Emax veneer give the average transmitted energy at the five different energy levels for the three different locations on the veneers. The tables also show the thickness of the veneers used for the transmission measurements (mean ± SD).

The veneer thickness of the EE veneers used for the energy transmission measurements ranged from 0.73 ± 0.12 to 1.39 ± 0.13 mm. The thickness of Emax veneers was very similar and ranged from 0.77 ± 0.12 to 1.31 ± 0.04 mm.

Tables 1 and 2 in addition show the energy transmission in percent. The EE veneers transmitted between 11.5% and 21% of the laser energy depending mainly on the veneer thickness. In contrast the Emax veneers transmitted more energy with a range between 26.5% and 43.7% of the irradiation energy. They transmitted roughly twice the energy at a comparable thickness.

For the EE veneers the linear regression curve fit calculated the slope of the line at -12.4 ± 5.3 for the lowest energy and -32.8 ± 1.3 for the highest energy, with $r^2 = 0.8435$ and $r^2 = 0.9985$, respectively. For the Emax veneers for the lowest energy the slope was calculated at -23.6 ± 2.1 and 53.7 ± 5.9 for the highest energy transmitted with $r^2 = 0.992$ and $r^2 = 0.9881$, respectively. The

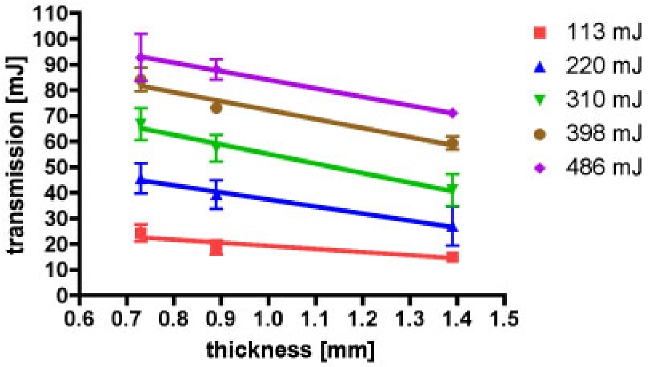

Fig. 3. IPS Empress Esthetics regular veneers; Energy transmission through different veneer thickness, with a veneer thickness of 0.73 ± 0.12 mm (thinnest area in the cervical third), 0.89 ± 0.03 mm (center of the veneer), and 1.39 ± 0.13 mm (thickest area at the incisal edge), allowing 11.5–20% of the laser energy to be transmitted; laser energy set at five different output setting (113, 220, 310, 398, and 486 mJ) at 10 Hz repetition rate; linear correlation fit with r^2 between 0.8435 and 0.9985.

high r^2 values represent a very high goodness of fit for the linear regression lines.

Thickness all study veneers. Table 3 shows the thickness of all 24 study veneers, and separated into EE and Emax. The thickness of the two different sets varied only slightly. At the incisal edge the veneers measured in average 1.18 ± 0.12 mm, in the middle 0.98 ± 0.07 mm, and cervical 0.76 ± 0.11 mm (mean ± SD) (Fig. 5).

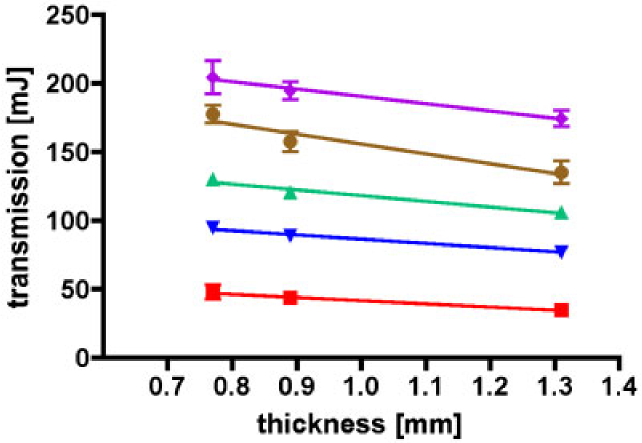

Fig. 4. IPS e.max Press HT regular veneers; Energy transmission through different veneer thickness, with a veneer thickness of 0.77 ± 0.12 mm (thinnest area in the cervical third), 0.89 ± 0.04 mm (center of the veneer), and 1.31 ± 0.04 mm (thickest area at the incisal edge), allowing 26.5–43.7% of the laser energy to be transmitted; laser energy set at five different output setting (113, 220, 310, 398, and 486 mJ) at 10 Hz repetition rate; linear correlation fit with r^2 between 0.992 and 0. 9881.

FTIR spectra of veneer cement. The FTIR spectra of the RelyX A1 cement revealed a strong peak most likely related to silica (1,100 wavenumber) as well as a C=O peak at 1,680/1,630 wavenumber. Moreover, the FTIR spectra demonstrated a broad H_2O/OH absorption band (wavenumber 3,750–3,640 and 3,600–3,400, respectively), which coincides with the Er:YAG laser emission wavelength (Fig. 6). Thus, the RelyX cement absorbs the Er:YAG laser irradiation and ablation of the cement will occur.

Cement ablation thresholds. The visual ablation threshold determination showed that using an Er:YAG laser RelyX shade A1 cement is ablated at fluences around 1.8–4.0 J/cm^2. Ablation fumes evolving from the cement surface were first seen at around 1.8 J/cm^2. Obvious ablation craters were detected at around 4.0 J/cm^2.

For verification of energy transmission through the veneer and possible consecutive ablation of cement, the standardized veneer samples were placed on cement samples and the distance to the veneer surface when first signs of ablation through the veneer occurred were evaluated. First signs of cement ablation through the standardized veneers happened at distances of the fiber tip to the veneer surface at 3–6 mm with 133 mJ per pulse at the fiber tip.

Laser Debonding of Veneers

IPS Empress Esthetic veneer debonding. All EE porcelain veneers were completely and easily removed from the tooth using the Er:YAG laser. The average removal time was 113 ± 76 seconds, while the removal time ranged from 31 to 290 seconds. In addition, the removal occurred without ablating or damaging any tooth structure according to the light microscopical imaging. Light microscopy revealed that the debonding mainly occurred at the cement/veneer interface (see below).

For the subset kept dry to simulate freshly placed/misplaced veneers, two of eight (25%) veneers fractured. For the subset immersed in saline for 5 days to simulate some short-term wearing conditions, two of three (66%) veneers fractured during the removal process. In total 64% of the EE veneers did not fracture during the removal process.

IPS e.max Press HT veneer debonding. All Emax veneers were also completely removed without damaging the tooth structure. The average removal time was 100 ± 42 seconds (range 48–205 seconds). Whether the cemented Emax veneers were stored dry or wet the removal procedure did not result in a visible or light microscope detectable fracture or damage to the veneer.

Veneer debonding—summary. In summary, all veneers were completely and easily removed using the Er:YAG laser. The veneers just slid off the tooth surfaces, they did not need to be pried off. If the veneer fractured during removal one part slid off typically followed by a maximum of one or two more pieces. Air spray was engaged to keep the fiber tip clean and for additional cooling of the substrate. Figure 7 shows the time needed to remove the veneers using the Er:YAG laser by employing

TABLE 1. IPS Empress Esthetic veneer thickness for transmission measurements

Area of the veneer	Mean ± SD (mm)		Energy applied (mJ) 131	227	318	406	482
Incisal	1.39 ± 0.13	Energy transmitted (mJ)	15.0 ± 1.9 (11.5%)	27.0 ± 7.6 (11.9%)	41.0 ± 6.2 (12.9%)	59.3 ± 2.6 (14.6%)	71.0 ± 1.7 (14.7%)
Middle	0.89 ± 0.03		18.6 ± 2.7 (14.2%)	39.3 ± 5.6 (17.3%)	57.3 ± 5.2 (18.1%)	73.0 ± 1.4 (18.0%)	88.0 ± 4.0 (18.3%)
Cervical	0.73 ± 0.12		24.3 ± 3.3 (18.5%)	45.6 ± 5.9 (20.1%)	66.7 ± 6.2 (21%)	84.0 ± 4.6 (20.7%)	92.7 ± 9.2 (19.2%)

Veneer thickness for transmission measurements incisal, middle, and cervical area on the veneer, energy applied and energy transmitted, percent of energy transmitted (in parenthesis) for IPS Empress Esthetic, three veneers.

TABLE 2. IPS e.max HT Press Veneer Thickness for Transmission Measurements

Area of the veneer	Mean ± SD (mm)		Energy applied (mJ) 131	227	318	406	482
Incisal	1.31 ± 0.04	Energy transmitted (mJ)	34.7 ± 4.1 (26.5%)	77.0 ± 5.4 (33.9%)	106.0 ± 12.5 (33.3%)	135.1 ± 21.9 (33.3%)	174.4 ± 15.5 (36.1%)
Middle	0.89 ± 0.04		43.8 ± 4.0 (33.4%)	89.0 ± 4.5 (39.2%)	120.5 ± 10.1 (37.9%)	157.5 ± 17.9 (38.8%)	194.7 ± 15.8 (40.4%)
Cervical	0.77 ± 0.12		47.8 ± 5.2 (36.5%)	94.7 ± 10.8 (41.7%)	130.3 ± 8.4 (41%)	177.6 ± 15.8 (43.7%)	204.4 ± 29.4 (42.4%)

Veneer thickness for transmission measurements incisal, middle, and cervical area on the veneer, energy applied and energy transmitted, percent of energy transmitted (in parenthesis) for IPS e.max HT Press, three veneers.

TABLE 3. Thickness of All Veneers and Separated Into Emax and EE Veneers

Area of the veneer	Empress Esthetics ($n = 11$), mean ± SD (mm)	IPS e.max Press HT ($n = 13$), mean ± SD (mm)	All veneers ($n = 24$), mean ± SD (mm)
Incisal	1.18 ± 0.05	1.18 ± 0.15	1.18 ± 0.12
Middle	0.97 ± 0.05	0.98 ± 0.09	0.98 ± 0.07
Cervical	0.70 ± 0.07	0.80 ± 0.11	0.76 ± 0.11

Thickness of all veneers and separated into Emax and EE veneers, respectively; mean and standard deviation at the thickest area at the incisal edge, an area in the middle third, and at the thinnest area in the cervical third of the veneer.

the lowest energy setting calculated from the ablation threshold determination. The removal time for a veneer averaged 106 ± 59 seconds and ranged from 31 to 290 seconds. The Emax veneers were removed slightly faster than the EE veneers but the difference in removal time was not significant ($P = 0.6$; unpaired *t*-test).

As a clinical guide to identify whether the distance of the fiber tip to the veneer surface is correct to cause ablation at each area of the veneer, a change in translucency of the veneer can be observed due to the ablation of the cement under the veneer. While painting with the laser from side to side over the veneer, its appearance changes from translucent to opaque at the irradiation site. If enough surface area is irradiated the veneer slides off.

Light microscopy revealed no damage to the tooth due to the laser debonding of the veneer. The light microscopical pictures showed that the debonding occurred mainly at the veneer/cement interface. The Incident Light Microscope images of the tooth surface after veneer debonding show that most of the visible surface of the tooth is covered with bonding cement. In several areas linear stripes of clean enamel surfaces can be seen (Fig. 8) (magnification 50×). They are comparable with the irradiation pattern used for the removal and reflect irradiated stripes. These areas between cement layers show enamel with no signs of ablation or damage at higher magnification (100×) (Fig. 9).

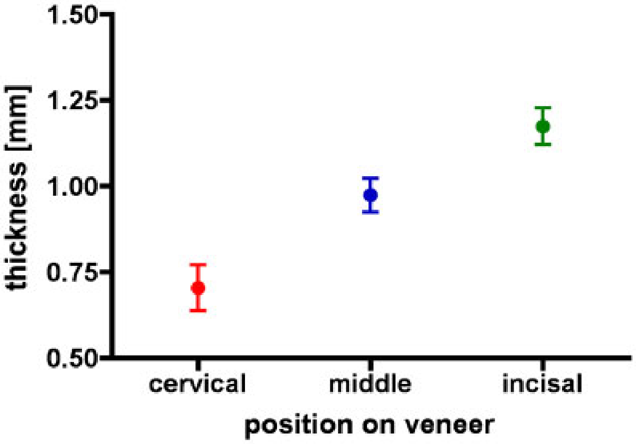

Fig. 5. Thickness of all study veneers (average and standard deviation), in the cervical, middle, and incisal area of the veneers.

DISCUSSION

The FTIR spectroscopy of RelyX shade A1 veneer bonding cement revealed besides a strong peak most likely related to silica and a C=O peak that the cement shows a broad H_2O/OH absorption band. This water absorption band coincides with the emission wavelength of an Er:YAG laser. In contrast, the FTIR spectra of freshly produced IPS Empress Esthetic and e.max HT Press veneers do not show this characteristic absorption band. Therefore, the assumption can be made that laser energy from an Er:YAG laser will not be strongly absorbed in a freshly produced veneer and thus can be transmitted through this veneer. The transmitted energy then will be absorbed in the bonding cement and will cause ablation of the cement similar to removal/ablation of composite fillings with the Er:YAG laser. Other veneer bonding cements should behave quite similarly to the tested one since composite fillings are already successfully ablated with Er:YAG lasers. An Er:YAG laser removes cured composite resin in a slightly different way than ablating dental hard substances. The ablation mechanism involved is explosive vaporization followed by a hydrodynamic ejection [12]. Rapid melting of the organic components creates large expansion forces due to the volume change of the material upon melting [13].

The measurements of laser energy transmission through the veneers at the thickest area at the incisal edge, an area in the middle, and at the thinnest area in the cervical third of the veneer showed that the IPS Empress Esthetic veneers transmitted between roughly 12% and 21% of the irradiated energy, depending mainly on the veneer thickness. Furthermore, it was shown that the IPS e.max HT veneers transmitted roughly twice as much energy at a comparable veneer thickness, resulting in a transmission of roughly 27% to almost 44% of the irradiation energy. Thus, removal of the Emax veneers from the energy transmission perspective will require less initial laser energy. The observed difference in energy transmission in the infrared wavelength spectrum must be originated in the different chemical composition of both veneer materials, one being a leucite glass-ceramic and the other one a lithium disilicate glass-ceramic, respectively.

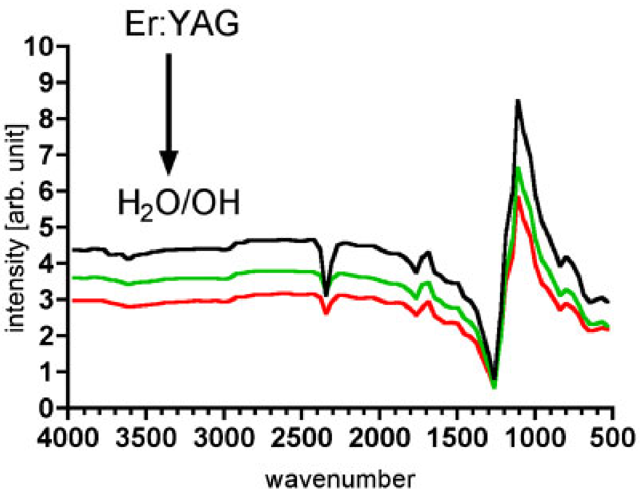

Fig. 6. FTIR spectra of three RelyX shade A1 cement samples exhibiting a strong silica peak (1,100 wavenumber), a C=O peak (1,680/1,630 wavenumber), and broad water/OH absorption band, coinciding with the Er:YAG laser emission wavelength (spectra from three samples overlaid).

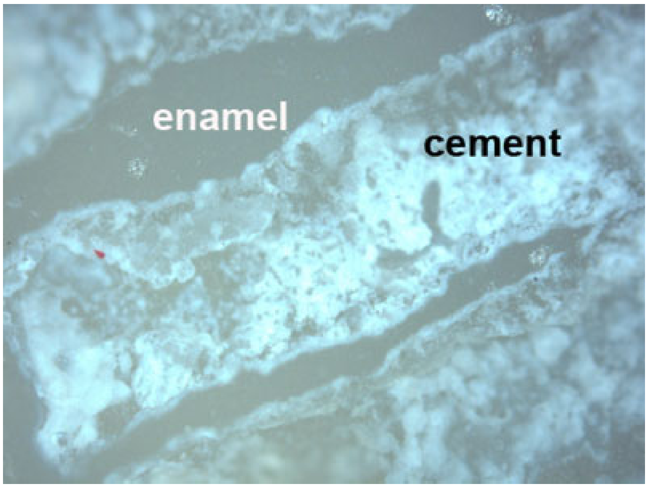

Fig. 8. Incident light microscope image of the tooth surface after veneer debonding showing that most of the visible surface is covered with bonding cement (50× magnification); irradiation pattern used for debonding is visible.

Combining the gained knowledge from the FTIR spectroscopy about absorption characteristics of veneers and cement, with the energy transmission data, in a next step standardized veneer samples were placed on top of cement samples in order to prove that Er:YAG laser irradiation through a veneer results in ablation of the bonding cement.

The surface of the veneers were perpendicularly irradiated with the Er:YAG laser, and ablation conditions for cement through the veneer were already achieved when the laser was set to the lowest laser output setting of 133 mJ per pulse, with a repetition rate of 10 Hz. Initial signs of ablation on the cement surface were detected when the irradiating laser fiber was kept in 3–6 mm distance from the veneer. These lowest laser settings applied at a typical Empress Esthetic veneer surface resulted in a fluence of 1.8–4.0 J/cm^2 at the cement surface, which caused the first signs of ablation of the cement. Since the Emax veneers demonstrated a higher energy transmission per given thickness, a larger distance to the veneer surface was needed to achieve the same low energy density.

When applying those low energies/fluences, all bonded veneers were completely removed from the tooth surface, thus the primary goal of the study was achieved. The incident light microscopic pictures revealed that the bond

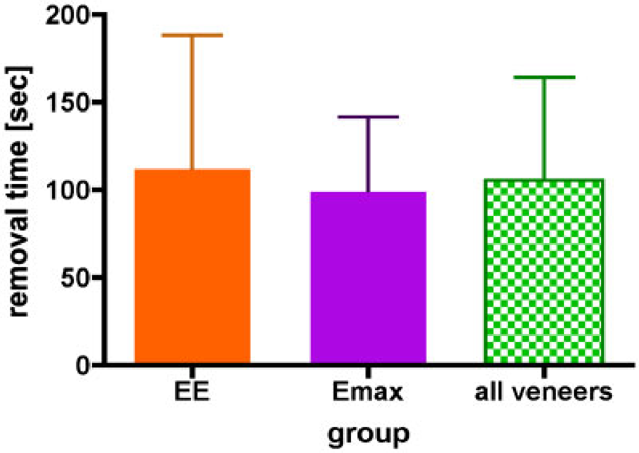

Fig. 7. Veneer removal time (mean ± SD) until complete removal of the veneer; the removal time for a veneer averaged 106 ± 59 seconds; there was no significant difference between the removal time for the two different veneer types.

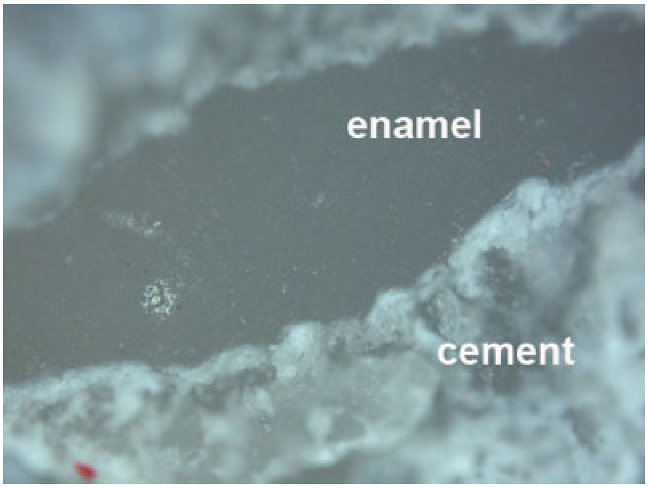

Fig. 9. Area between cement layers showing enamel surface at higher magnification (100×) with no signs of ablation or damage of the enamel.

between veneer and tooth enamel is disrupted mainly at the veneer cement interface therefore leaving the majority of the veneer clean. No damage or signs of ablation on the tooth surface were detected. The applied energies with resulting energy densities of <4.0 J/cm^2 are far below energies needed for enamel ablation [14,15]. Furthermore the light microscope showed as a result of the parallel laser-painting pattern for debonding stripes of clean enamel surface. This observation emphasizes that laser ablation rather than thermal softening of the cement achieves debonding of veneers. No slight marks of ablation or even ablation craters could be observed in the enamel. At this low energy level used for debonding, which is up to 20-times lower than energy needed for ablation of enamel, no signs of enamel ablation would be expected. The secondary goal of the study to debond veneers without aggressive destruction or removal of underlying healthy tooth structure was also attained.

The ablation mechanism for dental hard substances with an Er:YAG laser is based on the absorption of the laser energy in the small amount of water in enamel, followed by an explosive rapid water expansion [16,17]. In addition, when using the Er:YAG for hard substance removal as described, an air–water spray is applied to cool the substrate [18,19] as well as to prevent a stalling out effect [20,21].

When removing the Empress Esthetics veneers on average 36% fractured during the removal process. Even more fractures occurred when they were stored in saline solution for 5 days before debonding. Since porcelain is known to take up water, as it does when in the mouth over time [22–24], it would be understandable that the in saline solution stored veneers fractured more frequently and rapidly. Indeed, some of the saline solution stored veneers fractured only 3 seconds after laser application. Removing a dry-stored veneer without fracture took a minimum of 51 seconds. The assumption can be made that the almost immediate fracture of the saline-stored veneers occurred because enough water had entered the porous porcelain. The resulting rapid expansion/explosion of the water inside the veneer due to the applied laser energy caused the veneer to crack.

Interestingly, no IPS e.max Press HT veneer fractured during the laser removal process. Possibly this material is less porous and cannot store enough water in the short time given in this experiment. An even more likely explanation is that while the leucite glass-ceramic of Empress Esthetics shows a flexural strength of 160 MPa the lithium disilicate glass-ceramic of e.max Press HT features a flexural strength of 400 MPa. Thus, the latter can resist more easily the pressure build-up between the tooth and the veneer due to the explosive ablation of the cement, and the veneer does not fracture during the removal process.

Not fracturing the veneer during laser debonding could be an advantage in the rare occasion that a mishap occurred at the veneer bonding appointment and a veneer had been misplaced and needs to be repositioned. The light microscope showed no visible alterations of the veneer and bonding cement sticking to the veneer surface in multiple areas. Re-bonding would make it necessary to clean off the resin remnants from both the veneer and the enamel surface. Further research has to show whether that could be achieved “selectively” by using the Er:YAG laser for the resin removal without adverse effects to porcelain and enamel [25]. On the veneer side this is potentially achievable due to the fact that the porcelain appears to easily withstand fluences necessary to remove the resin. Re-etching and silanization will be needed. On the enamel side a method described as “Er:YAG laser finishing and smoothing” [26] might be utilized to clean up the enamel surface and prepare it for further bonding instead of finishing the surface with a fine diamond bur.

Future scanning electron microscopical investigations, which will provide better detailed information about the surface of the enamel and even more importantly about the veneer surface after laser debonding will be necessary to assess possible changes or damage of the veneer due to the ablation process. Those changes might not be visible in the low magnification light microscopical investigation. If there is microscopic damage, then reusing the veneer would be contraindicated.

Another observation hinting that the ablation pressure from cement ablation rather than from any water inside the porcelain results in a fracture is given by the fact that during energy transmission measurements through the veneer even at the highest possible laser energy settings no veneer fractured, neither EE nor Emax. The flexure strength of the veneer appears to be the key for preventing fracture of the veneer during laser debonding rather than any water uptake.

For the veneer removal mechanism it can be concluded that Er:YAG laser energy is transmitted through the veneer, and the transmitted amount depends on the veneer thickness and composition. The veneer resin cement absorbs the finally transmitted energy and already low fluences result in an ablation of the cement. When enough cement is ablated through the veneer it slides off the tooth surface. Depending on the pressure resistance of the veneer material (tensile strength of the veneer, e.g.) it slides off in one piece or in parts. It is also concluded that the resistance to pressure has a higher influence on the veneer stability than additional water—thus for pulpal safety a strong air–water cooling spray should always be engaged.

The veneer removal time ranged from 31 to 290 seconds with an average of 106 seconds. The third goal of this study was to prove that veneers can be removed without damaging them; for that reason speed of removal was of secondary importance. If the goal is just to remove the veneer and not keep the integrity of the veneer intact for instance due to caries at the veneer margins, the ablation process can easily be accelerated by applying slightly more energy. As reported up to 44% of the incident radiation was transmitted and could be measured behind the veneer while the remaining energy was (back)scattered through or reflected from the veneer. Using higher energies for veneer removal could also result in heating up of the veneer, which makes efficient air/air–water spray cooling necessary.

Since the laser energies that were applied (up to 4 J/cm^2) were far below those known to be safe for removal of enamel or dentin (80–160 J/cm^2) [5–8], and up to 20-times lower than those used for composite removal [10,11,27] the veneer removal process should also be safe for the pulpal tissue. It is generally accepted that a procedure is safe for the pulp if the pulpal tissue is not heated over 5°C [28]. In the dental office quick removal of failing, old veneers due to caries at the margins will be the main indication for laser veneer removal, any fracture of the "old" veneer will not matter and high amounts of air/water spray cooling should be applied. Nevertheless, pulp temperature measurements during veneer ablation should be conducted in the future.

This study was performed with a relatively small sample size. Nevertheless, all 24 veneers were effectively removed. A future study with a larger sample size might be able to distinguish differences between veneer materials. This might be of special interest in case of misplacing a veneer at the day of delivery and the attempt to remove it and place it immediately again.

In summary, limitations of the study at the present time are that only two different veneer materials were tested for energy transmission. Generally a wider variety of porcelains should be tested to assure that all kind of veneers can be debonded with the help of an Er:YAG laser. The same is true for veneer bonding cements. Multiple veneer bonding cements should be tested to allow generalization of the results. To assure pulpal safety, temperature measurements in the pulp chamber during veneer removal will be performed. If a dentist wants to have the flexibility of repositioning a wrongly placed veneer besides selecting the right veneer material, which allows this manipulation, more information about removal of composite remnants from the tooth as well as the veneer needs to be collected. Having those information will assure at least amongst Er:YAG laser users a wide adoption of this technique since it will be safe, easy to apply, and very time saving.

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