Laser Use in Creating Orthodontic Adhesion to Ceramic Surfaces

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Abstract: Orthodontists must sometimes bond attachments to ceramic crowns, by using one of the surface preparations available, such as sandblasting or acid etching with hydrofluoric acid. Research shows that different laser systems may also be used for this purpose. The aim of this review is to determine which laser type and modality of use is the most effective in increasing shear bond strength of brackets bonded to ceramic surfaces. Two independent researchers studied the current literature 1990–2018 and selected original articles focusing on in vitro research on laser use for ceramic surface preparation for bonding metallic or ceramic attachments. Twelve articles have met the criteria and have been thoroughly revised, focusing on ² fractional, Nd:Yag, Er:Yag, femtosecond and Ti:Sapphire lasers. There is little difference shown by the current studies between ceramic types and information on orthodontic bonding to non-feldspathic ceramics is scarce. Femtosecond laser is a good alternative to classical surface preparation with hydrofluoric acid. Nd:Yag laser is more suitable for surface preparation of ceramics than different types of Er:Yag lasers. Difference in laser power may achieve different results, but the golden standard for lasers use has not been found. Laser usage does not obtain the same results as hydrofluoric acid and cannot, so far, eliminate its application.

Citation: Labunet, A.; Kui, A.; Sava, S. Laser Use in Creating Orthodontic Adhesion to Ceramic Surfaces. *Appl. Sci.* **2021**, *11*, 2512. <https://doi.org/10.3390/app11062512>

Academic Editor: Mary Anne Melo

Received: 12 February 2021

Accepted: 8 March 2021

Published: 11 March 2021

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Keywords: laser; orthodontics; ceramics

1. Introduction

Introduction of lasers in dentistry was announced in 1960, by Miaman [1] and its use was continuously extended and researched. There are hard lasers, such as, carbon dioxide (CO₂), neodymium yttrium aluminium garnet (Nd:YAG), erbium-doped yttrium aluminium garnet laser (Er:YAG) and cold or soft lasers which are known as low-level laser therapy or ‘biostimulation’ [2]. In order to ensure laser efficacy on a certain surface, an adequate intensity on the surface must be obtained. Also, it should couple as high a fraction of incident power into the material as possible. Laser beam properties, that may influence these characteristics, are: wavelength, responsible for the focusability and absorptivity of the beam; power and achievable spot diameter, which determine the intensity in the interaction zone; beam quality, being a measure of the available focused spot diameter and beam divergence angle product; finally, the polarisation of the beam, which has a considerable influence on the absorptivity for large angles of incidence [3].

Lasers may be used for most of the common dental procedures, such as frenectomies, crown lengthening, composite curing, and control of haemorrhage disorders, caries detection and removal, reduction of pain and treatments of hypersensitivity, gingivectomy, gingivoplasty, soft-tissue lesions and aphthous ulcers [4].

A short presentation of lasers used in dentistry facilitates understanding of this review [5]. The CO₂ laser wavelength has a very high affinity for water, resulting in rapid soft tissue removal and haemostasis with a very shallow depth of penetration. Its disadvantages are its large size and high cost and destructive interactions with hard tissue.

The Nd:YAG wavelength is an effective surgical laser for cutting and coagulating dental soft tissues, with good haemostasis, that has also been used in periodontal treatments.

The erbium lasers have two distinct wavelengths, Er Cr:YSGG (yttrium scandium gallium garnet) lasers and Er:YAG (yttrium aluminium garnet) lasers, with a high affinity for hydroxyapatite and the highest absorption of water in any dental laser wavelengths, thus being used for the treatment of dental hard tissues [6]. Erbium lasers can also be used for soft tissue ablation [7].

The diode laser has an active medium made of aluminium, gallium, arsenide and indium. It is mostly used for aesthetic gingival re-contouring, soft tissue crown lengthening, exposure of soft tissue impacted teeth, removal of inflamed and hypertrophic tissue, frenectomies and photostimulation of the aphthous and herpetic lesions [8]. One of the diode laser types that is also used in dentistry is titanium-doped sapphire. It is a widely used gain medium, with an active ion which has a large bandwidth in a host crystal that is hard and has high thermal conductivity [9].

A femtosecond laser emits optical pulses with a duration in the domain of femtoseconds—1 ps. It is included in the category of ultrafast or ultrashort pulse lasers. Femtosecond pulsation may be obtained by various diode-pumped lasers, such as neodymium-doped or ytterbium-doped gain media. Diode lasers and titanium-sapphire lasers are also suitable for pulse durations below 10 fs [3].

Other classifications of lasers are presented in Table 1.

Table 1. Different lasers classifications.

Operating mode	Laser Classification	
	Continuous	Q-switching mode-locking pulsed pumping (FS)
Lasing medium	Pulse	
	Gas laser	Argon 488–515 nm CO ₂ laser 9.3, 9.6, 10.6 nm Nd:YAG 1064 nm
	Solid laser	Er: YAG 2790–2940 nm Er:CrYSGG 2780 nm Ti: Sapphire 650–1180 nm
	Semiconductor	Crystals Diode 812–1064 nm
Tissue type	Hard	CO ₂ laser Nd:YAG Er:YAG
	Soft	Diode laser Argon

In orthodontic practice, lasers have many common applications, including acceleration of tooth movement, bone remodelling, enamel etching prior to bonding, debonding of ceramic brackets and pain reduction after orthodontic force and prevention of enamel demineralisation or soft tissue modelling [10].

At times, orthodontists must bond attachments to ceramic crowns, as they are commonly used in prosthodontic procedures. This type of bonding may cause some concerns, as there are several types of surface preparations that may be used. Surface roughness is needed for creating microretention for the adhesive layer used to bond brackets. Traditionally, surface roughness was gained by sandblasting or acid etching with hydrofluoric (HF) acid. With the development of laser systems, research focused on this technique for surface etching of ceramics in order to evaluate its efficacy [11].

This review aims to assess research, creating a thorough image of laser use in ceramic restorations for bonding orthodontic attachments. Adhesion of orthodontic attachments may be tested easily and thoroughly, as their small bonding surface of just a few square mil-

limetres and the possibility to debond without breaking the ceramics gives the opportunity of new research.

2. Materials and Methods

Two independent researchers searched Pubmed, Medline, Embase databases in February 2018, focusing on the bonding process of orthodontic attachments to ceramic surfaces by using search terms such as ceramics bond orthodontics, ceramics adhesion orthodontics. Articles published in the time frame 1990–2018 were revised. This search line was then limited to laser use in preparing a bonding surface on the ceramics. Only original articles were selected for this study. Exclusions concerned bonding to non-ceramic surfaces or bonding to ceramic surfaces that are not destined for orthodontics, laser usage for bracket base preparation. Exclusions have been made by reading titles and abstracts. Only experimental, in vitro studies, have been included, as clinical studies are difficult to reproduce and the influence of several factors, different use of appliances, doctor's capabilities, varies. Researchers finally listed articles that focused on bonding brackets of metallic and ceramic types to ceramic surfaces by means of a laser appliance.

3. Results

After the search has been performed, a total number of 314 articles have been found. After applying the inclusion and exclusion criteria, twelve articles were included in the process of revision. They are presented in Table 2.

Table 2. Articles of laser usage for bonding to ceramic surfaces.

No Ref.	Ceramic Type	Samples No	Bracket Type	Laser Type	Adhesion Type	Results	Additional Examination
[12]	Zirconia	180	Metallic	Ti:sapphire Femtosecond	Control/air particle abrasion/femtosecond laser 300 mW, 60 µm/Fs laser 200 mW, 100 µm/Fs laser 40 mW, 60 µm/Fs laser 200 mW, 60 µm	FS laser 300 mW, 60 µm and FS laser 200 mW, 60 µm higher SBS, 200 mW, 60 µm ideal FS settings	
[13]	Zirconia	300	Metallic and ceramic	Ti:sapphire Femtosecond	Control/APA/silica coating and silane (SC)/femtosecond laser (FS)/APA+FS	SBS sgn higher for ceramic brackets in all groups APA+FS > APA > FS > SC > control Metallic brackets, groups SC, FS, APA+FS sgn higher SBS than other groups. FS increases SBS to metallic and ceramic	Thermal imaging camera for temperature changes
[14]	Feldspathic, IPS Empress e-Max	150	Metallic	Ti:sapphire, Er:YAG, Nd:YAG	Ti:sapphire/Er:YAG/Nd:YAG, sandblasting/HF, light cure adhesive	Feldspathic similar to IPS Empress e-Max Ti:sapphire>sandblasting>HF Er:YAG similar to Nd:YAG, lower values	Thermocycling, SEM SEM showed regular surfaces obtained for Ti:Sapphire
[15]	Feldspathic	80	Metallic	Fractional CO ₂ laser	Fractional CO ₂ laser for 10 s 10 mJ, 200 Hz and powers of 10 W/15 W/20 W/9.6% HF 2 min.silane for all, deglazing for half of specimens	Deglazing sgn increased SBS of laser treated porcelain surfaces, but no sgn effect on SBS when using HF. SBSs 10 W and 15 W laser groups sgn higher than HF group	
[16]	Feldspathic	48	Metallic	Nd:YAG	Control/HF/grooved/0.75 W laser/1.05 W/1.45 W	Nd:YAG 1.05 W and HF could increase the bonding SBS and TBS, SBS and TBS—correlated	
[17]	Feldspathic	60	Metallic	Er:YAG Er:CrYSGG	9% HF 2 min/9% HF 2 min + Er:CrYSGG laser/9% HF 2 min + Er:YAG laser/Er:CrYSGG laser/Er:YAG laser. Transbond XT primer + adhesive for all	Sgn difference in SBS between the first three groups and the two laser groups. Er:YAG laser 3-W power, 10-Hz frequency for 10 s is not an alternative to HF. Er:CrYSGG laser, met minimal criteria 6–8 MPa	Thermocycling 5000 cycles SEM

Table 2. Cont.

No Ref.	Ceramic Type	Samples No	Bracket Type	Laser Type	Adhesion Type	Results	Additional Examination
[18]	Feldspathic	42	Metallic	Er:YAG	APA/9.6% HF/Er:YAG irradiation (2 W, 10 Hz for 10 s).	Er:Yag = HF > APA	
[19]	Feldspathic	150	Metallic	Er:YAG short pulse and super short pulse	5 groups RelyX U 200, 5 groups Transbond XT. APA/Er:YAG short pulse SP/Er:YAG laser super short pulse SSP/sandblasted+SP/sandblasted+SSP	Er:YAG laser did not allow the elimination of HF. RelyX U 200 an alternative to Transbond XT on sandblasted porcelain. Highest SBS sandblasting and Transbond XT.	
[20]	Feldspathic	100	Metallic	Er:YAG lasers	Deglazing, silane for all, 9.6% HF/Er:YAG lasers of 1.6, 2, and 3.2 W	Mean SBS in the laser group with power of 1.6 W > HF, 2-W power, 3.2-W power groups, but not sgn	
[21]	Feldspathic	80	Metallic	Ti:sapphire femtosecond, Nd:YAG laser	Ti:sapphire femtosecond/ APA/9.6% HF/Nd:YAG laser, silane for all	Group Nd:YAGsgn lower than the other groups, no sgn differences between the other groups.	Thermocycling 500 cycles
[22]	Feldspathic	72	Metallic	Nd:YAG	9.6% HF 4 min/0.75-, 1-, 1.25-, 1.5-, and 2-W Nd:YAG for 10 s.	No sgn differences between HF lasers with power of 1.5 or 2 W; no sgn difference between all test groups in ARI scores	Thermocycling 500 cycles
[23]	Feldspathic	100	Metallic	Nd:YAGEr:YAG	Diamond bur/9.6% HF 4 min/0.8-W Nd:YAG/2-W Er:YAG/3-W Er:YAG laser for 10 s	SBS in groups HF and 0.8-W Nd:YAGsgn higher	

4. Discussion

As dental ceramics are rigid, brittle and crack sensitive, but highly aesthetic and versatile, they are continuously evolving. Because of the improvement in strength of more recent, machined ceramics, dentists can use them not only for veneers, full or partial crowns, but also for implant abutments, bridgework and orthodontic brackets [24]. In 2015 Gracis et al. published a classification of dental ceramics dividing them into two main categories—glass matrix ceramic and polycrystalline ceramics [25]. A short classification of dental ceramics and their clinical indications is shown in Table 3.

Table 3. Types of ceramics and their clinical indications.

	Type of Ceramic	Clinical Indications	Etchable (Yes/No)
Glass matrix ceramics	Feldspathic	Veneer restoration	Y
	Leucite-based	Veneer restoration, partial crowns and anterior full crowns	Y
	Lithium disilicate	Veneer restoration, partial crowns and anterior and posterior full crowns	Y
	Alumina	Anterior and posterior full crowns	Y
	Alumina and magnesium spinel	Anterior full crowns	Y
	Alumina and zirconia	Anterior and posterior full crowns	Y
Polycrystalline ceramics	Alumina	Veneer restoration, anterior and posterior full crowns	N
	Stabilised zirconia	Partial crowns and anterior and posterior full crowns	N
	Zirconia-toughened alumina Alumina-toughened zirconia	Partial crowns and anterior and posterior full crowns	N

Glass matrix ceramics consist of metallic and silica oxides within a glassy matrix, meaning they can be attacked by acids such as acidulated phosphate fluoride (APF) or hydrofluoric acid [24]. Among the glass matrix ceramics, some types are widely used even today (feldspathic, lithium disilicate, alumina), although the manufacturers are constantly working on improvements. In order to prevent the dispersion of cracks through the glass matrix, stronger polycrystals or crystalline structures are inserted into the material [24].

Contrary to glass matrix ceramics, polycrystalline ceramics (alumina, stabilised zirconia, zirconia-toughened alumina or alumina-toughened zirconia) do not contain any glass, and as a result, they are not etchable. All the atoms are included into a regular crystalline array through which it is much more difficult for cracks to disperse, compared to glass ceramics. Polycrystalline ceramics were not available in dental practice until the late 1980s when the computer-aided manufacturing was developed [24,26].

In dental practice, ceramics can be used as all-ceramic restorations or metal-ceramic. For metal-ceramic restorations, feldspathic ceramics are used to cover a metal coping. Clinical experience suggests the veneering ceramic should be about 1–2 mm thick for adequate strength and aesthetics.

Whether a type of ceramic is etchable or not is important not only in prosthodontics but also for orthodontic treatments, as the adhesion between an orthodontic bracket and a prosthetic restoration is important for the treatment's success [24].

There are several surface conditioning techniques commonly used for bonding on zirconia restorations, such as silica coating [27] sandblasting [28,29], or laser irradiation with CO₂, Nd:YAG, or Er:YAG [30–33].

CO₂ lasers have a gas active part which emits at a wavelength of 10.6 nm which is absorbed by water and hydroxyl apatite, but also by ceramic materials and it can create micro-cavities using superficial heat, enhancing the strength between resins and ceramics. Nd:YAG lasers determine melting and random re-crystallisation, determining surface roughness and increasing the strength of resin-ceramic bond [33].

However, there is still to be established an ideal surface-treatment that will provide sufficient bond strength to minimise bracket debonding from polycrystalline ceramic restorations. In this context, the aim of our research was to create a thorough image of laser use in ceramic preparation for bonding orthodontic attachments, as it is not always possible to use hydrofluoric acid for surface preparation of the ceramic restoration already placed intra-orally.

The original articles included in this review used a similar procedure for bonding brackets to ceramics: creating a ceramic surface of either feldspathic, zirconia or IPS Empress E-max type, bonding brackets using an orthodontic adhesive, mostly Transbond XT as the golden standard and debonding the bracket using an Instron machine that also measures shear bond strength. In some studies, thermocycling from 500 to 5000 cycles was used to create an environment that is similar to the oral cavity, as thermocycling influences adhesion. Some studies also searched the debonded ceramic samples under a scanning electron-microscope in order to find surface irregularities or cracks.

4.1. The Effect of Laser on Non-Feldspathic Ceramic

Only few articles focus on more recent types of ceramics, as most are developed on feldspathic porcelain. Two articles, *in vitro* research done by the same team lead by García-Sanz, focus on zirconia ceramics [12,13]. Both studies used Ti: sapphire femtosecond laser for surface preparation. In [12], 180 samples were bonded with metallic brackets, testing mainly the intensity of the femtosecond laser; the conclusion reached was that the ideal setting is 200 mW. In the other study published by Garcia-Sanz et al., the authors focused on comparing femtosecond laser surface preparation to other types of roughening, such as air particle abrasion, silica coating and silane, and a combination of air particle abrasion and femtosecond laser. The ceramic bracket groups had higher shear bond strength values in all groups and femtosecond laser proved to be beneficial either alone or in combination with air particle abrasion for both type of brackets [13].

An article published in 2015 [14] compared feldspathic ceramics to IPS Empress E-max when using several types of lasers for surface preparation. The two types of ceramics showed similar shear bond strength values in all groups. Ti:sapphire laser showed higher SBS than sandblasting, and even higher than hydrofluoric acid. The ER:YAG and Nd:YAG laser had similar, lower results.

4.2. The Effect of Laser on Feldspathic Ceramic

Feldspathic ceramic is most commonly included in studies, as it is most often used in prosthodontics [15–23]. Only one research, published by Ahrari in 2013 [15], focuses on fractional CO₂ laser use by testing different intensities of 10 W, 15 W, 20 W and comparing them to hydrofluoric acid. The results obtained showed that the shear bond strength obtained by using 10 and 15 W laser was significantly higher than the acid group; deglazing, meaning the removal of the smooth exterior layer of ceramics, helped in laser-treated ceramic surfaces. Removing the glaze layer of the restoration is considered to generally achieve better adhesion in laser-treated ceramic surfaces, as the high amounts of energy emitted by lasers seem to be better absorbed by the opaque surfaces [33]. By thermocycling for 5000 cycles, the reliability of the study developed by Mirhashemi [17] increases, concluding that combined use of HF and laser achieved significantly higher shear bond strength than laser groups and just Er:CrYSGG laser met minimal criteria for orthodontics, when used alone. Aksakalli and his team [18] showed in 2015 that Er:Yag and hydrofluoric acid had similar results, higher than air particle abrasion, which contradicts a study published in 2013 [19], that shows Er:Yag does not allow us to eliminate hydrofluoric acid application. Yassaei, in 2013 [20], shows that Er:Yag with power of 1.6 W had higher SBS than hydrofluoric acid or 3.2 W power. When testing feldspathic ceramics with Nd:Yag laser and Ti:Sapphire Femtosecond laser, Akpınar [21] shows that this type of laser is relatively ineffective compared to hydrofluoric acid, air particle abrasion and femtosecond laser, but Hosseini [22] contradicts these results, showing similar results of the same type of laser to hydrofluoric acid.

When comparing Nd:Yag to Er:Yag, Poosti and his team [23] show better, significantly higher results for Nd:Yag.

5. Conclusions

There is little difference shown by current studies between ceramic types, however newer, machined ceramics, such as zirconia and E-max are least researched in terms of orthodontic bonding.

Femtosecond laser is a good alternative to classical surface preparation by sandblasting or acid application. Nd:Yag laser is more suitable for surface preparation of ceramics than different types of Er:Yag lasers. Different power may achieve different results, but the golden standard for lasers use has not been found. Laser usage does not provide the same expected results as hydrofluoric acid. Some similar studies have opposing results. Thermocycling is not used in many studies and it may influence the results by greatly influencing adhesion. Further research is needed on newer types of ceramic and a laser use protocol has to be established in order to facilitate laser usage for surface preparation of the ceramics.

Author Contributions: Conceptualisation, A.L. and A.K.; methodology, A.L., S.S.; software, A.K.; validation, A.L., A.K., S.S.; investigation, A.L., A.K.; data curation, A.K.; writing—original draft preparation, A.L.; writing—review and editing, A.K., S.S.; supervision, S.S.; project administration, A.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

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