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ORIGINAL ARTICLE

The lingual enamel morphology and bracket shear bond strength influenced by Nd:YAG laser and aluminum oxide sandblasting preconditioning

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Abstract

Objectives This study aimed to investigate the influence of Nd:YAG laser and aluminum oxide sandblasting on the shear bond strength (SBS) of lingual brackets and to optically analyze the behavior of the enamel morphology.

Materials and methods Thirty-five bovines' incisors teeth were divided into 5 groups ($n = 7$), according to the surface preconditioning: G1, control group; G2, Nd:YAG laser; G3, laser + aluminum oxide sandblasting (Al_2O_3); G4, Al_2O_3; and G5, Al_2O_3 + laser. All groups had lingual brackets bonded and shear debonded after 72 h. SBS values were analyzed, and the enamel morphology was evaluated by optical coherence tomography (OCT) and scanning electron microscope (SEM), before and after preconditioning surface. The optical attenuation coefficient (α) analysis was obtained from OCT images. Data analysis used the ANOVA test, followed by post hoc Tukey, Kruskal Wallis, and post hoc Dunn tests (significance of 5%).

Results The SBS values presented similarly among groups, but the value of α showed statistical difference (p-value = 0.0124) between G3 and G5 with the others. Optical analyses indicated a melting on the enamel that suffered laser irradiation for G2 and G5 and crystal surface disorganization for G4. Sandblasting partially removes the melting of the laser effect (G3).

Conclusion The sandblasting is a dispensable step for bonding lingual brackets, and the melting of the enamel after laser irradiation does not compromise the bracket adhesive resistance.

Clinical relevance The Nd:YAG laser became an interesting tool to prevent caries and decrease prevalence of white spot lesions in orthodontic treatments, without systemic effects in patients with genetic high risks of caries.

Keywords Dental enamel · Brackets · Optical coherence tomography · Laser · Lingual orthodontics · Sandblasting

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Introduction

Background

Dental caries is a chronic infectious disease that affects billions of people worldwide, with large individual differences in disease activity. It is estimated that 20% of the population has caries by genetic factors that have not enough response to fluor therapy and hygiene habits, being indicated intensified traditional prevention and immunostimulatory therapeutics [1]. In general, orthodontic brackets are considered a risk factor of white spot lesions (WSL) because it allows plaque accumulation around the appliance [2], which is one of the main etiologic factors of the WSL, followed by acid production and loss of tooth calcified substance [3]. About 75% of the orthodontic patients have an incidence of WSL, and recently, 4.6% of the global economy is a burden of dental diseases [4].

The introduction of lingual brackets, in the 1970s, came to improve the aesthetic of the patient during treatment. However, the diminished inter-bracket distance and the gum proximity of the bracket position decrease the cleaning efficiency and increase the WSL's risks [5]. Usually, the base of prototyped lingual bracket covers the whole lingual surface and decreases this risk [6, 7]. However, patients wearing non-prototyped lingual brackets showed more plaque retention and *S. mutans* counts after bonding, even more than buccal appliances [8], as it intensifies the risk of caries disease. Additionally, the lingual enamel is thicker than the buccal [9] and, once installed, could increase the caries propagation to the other tissues.

During the lingual bracket bonding, the initial protocol includes the aluminum oxide sandblasting [10] before the acid etching to increase the surface contact area [11–15]. After acid etching, the enamel demineralization that promotes superficial hydroxyapatite loss and porosities is considered a WSL risk factor. To minimize these lesions is indicated fluoride application directly onto the enamel adjacent to bracket [16], associated with bonding materials [17] or with laser irradiation [18, 19]. The ability of Nd:YAG laser to promote fluoride uptake and prolong its releasing time in an oral environment points to a demineralization resistance with reduction of caries potential up to 45.9% [20].

The laser irradiation changes chemically and morphologically the enamel surface that could influence shear bond strength (SBS) of the brackets. To guarantee the SBS during the treatment, the enamel should be prepared to assure SBS of brackets between 5.9 and 7.8 MPa [21]. No studies have reported if the changes on enamel after lasing disturb the SBS of lingual brackets and if the aluminum oxide sandblasting allows the SBS to increase without removing the laser effect of enamel protection.

Objectives

The aim of this study was to investigate the influence of Nd:YAG laser and/or aluminum oxide sandblasting on the shear bond strength of lingual brackets for direct bonding. Optical evaluation of the enamel behavior was carried out before, during, and after procedures, through noninvasive optical analysis.

Materials and methods

This study was carried out after approval by the Animal Ethics Committee from IPEN (CEUA-IPEN/SP n. 107/12). Thirty-five bovine incisor teeth, free from caries, cracks, fractures, deep dental grooves, surface decalcification, abrasions, and stains, were selected and disinfected with 1 % chloramine-T solution (7 days) (ISO/TS11405) and stored in deionized water at 4 °C [22].

The specimen size caculation [23], the equation $N = 4\sigma^2 (Z_{crit} + Z_{pwr})^2 / D^2$ was used, where N is the total specimen size, σ is the standard deviation (value 0.204), Z_{crit} is the significance level (1.96, for 5% significance), Z_{pwr} is the statistical power (1.282, for study power of 90 %), and D is the expected mean value difference (equals to 0.5). This calculation resulted in approximately 7 specimens per group.

Specimens' preparation

Approximately 2 mm of the incisal surface was removed from the teeth with a diamond disc (Pretty Dental, São Paulo, Brazil) mounted in the micromotor and handpiece to standardize the positioning of brackets and the shear bond strength procedure (Fig. 1). The groups were divided according to the preconditioning methods of lingual surfaces (*n = 7*): G1, control group; G2, Nd:YAG laser irradiation; G3, Nd:YAG laser irradiation and aluminum oxide sandblasting; G4, aluminum oxide sandblasting; G5, aluminum oxide sandblasting and Nd:YAG laser irradiation.

Orthodontics lingual brackets (Forestadent, Pforzheim, Germany) with quadrangular base were used by a mesh with dimensions of 3.26 mm × 3.26 mm (base area, 10.62 mm^2).

The aluminum oxide sandblasting (50 μm, 60 psi, BIO-ART, SP, Brazil) was applied perpendicular to the tooth lingual surface, within the distance of 10 mm during 3 s [11].

For pulsed laser irradiation (Nd:YAG laser Power TM ST6, Lares Research®, USA), the lingual surfaces were covered with a thin layer (~ 100 μm) of a photoabsorber composed of triturated coal (particles of ± 10 μm diameter) diluted in equal parts of deionized water, and 99% ethanol [20] specimens were irradiated twice in manual contact: once in a horizontal way and the other in a vertical way (30 s each) to guarantee that all the surface was irradiated as per clinical application. The employed laser protocol is shown in Table 1.

All teeth were cleaned with pumice stone (SSWhite Duflex, Rio de Janeiro, Brazil), then washed (10 s), air dried (10 s) and the bracket bonded after respective pretreatments, according to the manufacturer instructions (kit Transbond XT/ Lot: N821727/3M Unitek, Monrovia, CA, USA), including 37 % phosphoric acid etching (Condac, FGM, Joinvile, Brazil) for 30 seconds on the designated space for bonding, followed by water spray (10 s), air dried (10 s), primer application, primer photoactivation (20 s) and resin application on the brackets base for positioning on the tooth surface.

To standardize the resin flow before the curing, an adapted tensiometer (Morelli, São Paulo, Brazil) was used with 1200 gf for 5 s, and all the excesses of resin were removed by an exploratory probe. The LED curing unit (LED Ortholux™ Luminous Curing Light; 3M ESPE, Minnesota, EUA) had 1600 mW/cm^2 of irradiance tested before the experiment,

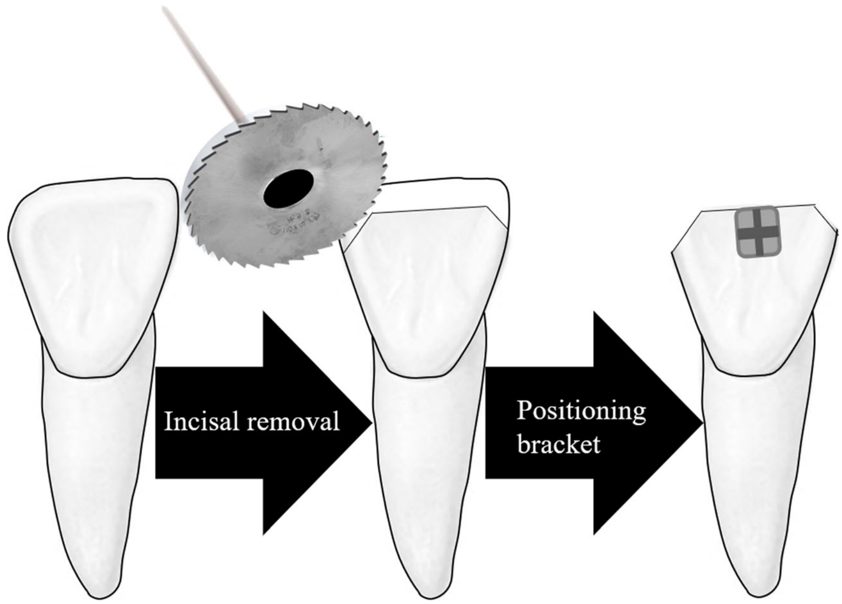

Fig. 1 Schematic drawing of the incisal tooth surface removal to help positioning the brackets

and the photoactivation was done for 10 s on each side of the brackets (distance of 2–3 mm).

After 24 h of storage in deionized water, specimens were vertically embedded in a chemically activated acrylic resin (Jet, São Paulo, Brazil) aided by a device for specimens' inclusion (useful tip section of 5 mm × 0.5 mm, Odeme, 467, Santa Catarina, Brazil). After inclusion, another 48 h storage occurred in deionized water, totalizing 72 h between the bonding procedure and the shear bond strength.

Shear bond strength analysis

The shear bond strength test was performed according to ISO/TS11405 by a universal test machine (Instron 5567, Texas, EUA) with 1 kN cell load and 0.5 mm/min speed. Specimens were positioned for the chisel to have contact with the bracket-adhesive-enamel interface when sliding in a parallel vector to the bracket's base until it fractures or the adhesive bond breaks. The force was recorded in Newtons (N) and divided by the base bracket area in order to obtain the resistance value of shear bond strength in megapascal (MPa).

Table 1 Parameters of Nd:YAG laser irradiation

Laser	Nd:YAG
Wavelength	1064 nm
Average power	0.6 W
Pulse frequency	10 Hz
Width of pulses	100 μs
Pulse energy	60 mJ
Energy density (fluency)	84.9 J/cm^2
Duration of the irradiation	30 s
Fiber diameter	300 μm

Scanning electron microscope (SEM) analysis

For each stage, the groups were evaluated by low vacuum SEM (Hitachi TM3000, Tokyo, Japan) to analyze the enamel surface morphology. It was operated with 15 kV, and images were captured and analyzed at magnitudes of × 3000.

Optical Coherence Tomography (OCT) analysis

An OCT system, OCP930SR (Thorlabs Inc., NJ, USA), produced cross-sectional (2D) images from the scanned specimens. The base unit contains a light source, a superluminescent diode (SLD), operating at a central wavelength of 930 nm, with a spectral width of 100 nm and 29 kHz A-scan rate, and it can capture 8 frames per second (fps), composed of 512 lines, 2000 columns, and axial resolution of 6.2 μm. The generated images had 6 mm of transverse scan, and the distance between the cuts and measurements in the cervico-incisal direction was 1 mm. The enamel refractive index considered was 1.6 [24].

Optical attenuation coefficient (α)

A custom software using MATLAB programming language (MATLAB, MathWorks Inc, Massachusetts, USA) was specially developed to analyze the optical decay of specimen images obtained by OCT. The software identifies the air-specimen interface. The operator selects a region of interest (ROI) delimiting the analysis where the average A-scan was calculated after aligning the A-scan by the air-specimen interface. An exponential fit, based on Beer's Law, was applied to average A-scan to obtain the α. This analysis was repeated for several sequential acquisitions giving an arithmetic α value for each group. It calculated the variation (Δ) considering the final average values (T1—immediately after the group's preconditioning) minus initial average values (T0—before any treatment), for intergroup comparison [24].

Data analysis

Shapiro-Wilk normality tests were performed to verify the normality of obtained data with a significance of 95% (power of 90%). For intergroup comparison of SBS data, the ANOVA and post hoc Tukey tests were done (considering normal data and unpaired tests). For the optical attenuation coefficient, the Kruskal Wallis test and the post hoc Dunn test were used. Tests were performed in the GraphPad Prism software (version 6 for MacOS, GraphPad Prism Software, California, USA).

Results

Shear bond strength

The shear bond strength demonstrated the difference in the intergroup comparison (p-value = 0.0034) (Table 2). The post hoc comparison between groups showed differences between G3 and G2 (p-value = 0.0155) and G5 and G2 (p-value = 0.0050) and no differences between the other groups: G1/G2 (p-value = 0.9912), G1/G3 (p-value = 0.8779), G1/G4 (p-value > 0.9999), G1/G5 (p-value = 0.4107), G2/G4 (p-value = 0.2031), G3/G4 (p-value > 0.9999), G3/G5 (p-value > 0.9999), and G4/G5 (p-value > 0.9999).

SEM and OCT

The analysis of the enamel superficial morphology by SEM resulted in the images shown in Fig. 2. By SEM analysis, G2 presented a fusion and recrystallization of enamel surface (melting). In G3 and G4, surfaces showed roughness and irregularities, with multiple elevations, different heights, and rounded borders, showing superficial depressions of the particles impact, with linear forms. In G5 the surface presented the aspect of a few enamel fusions associated with micro-craters and some cracks.

Through OCT images (Fig. 3), it was observed that the laser melting effect in G2 was present as dense points on enamel surface line. In the specimens of G4, the effect of aluminum oxide sandblasting was represented as a large straight refraction area under the enamel surface line showing a different optical decay from G3 that sandblasting effect was more concentrated in points on the sub-superficial layer and less reflective. In G5, the center of the image presented less optical decay than lateral areas, but nevertheless, it also presents interleaved areas of higher optical decay.

Optical attenuation coefficient (α)

The analysis of the variation (Δ) on the optical attenuation coefficient α showed a statistically significant difference (p-value = 0.0124) among the groups G5/G2 (p-value= 0.0420) and G5/G4 (p-value = 0.0498) and no differences between the others: G2/G3 (p-value = 0.3605), G2/G4 (p-value > 0.9999), G3/G4 (p-value = 0.4096), and G3/G5 (p-value > 0.9999). The G3 and G5 were similar and both presented a decrease in their final α values, while G2 and G4 had increased (Table 3).

Discussion

The present study is, to the best of our knowledge, the first that reports the SBS for direct bonding on the lingual surface of anterior teeth with lingual brackets. It was motivated by the increased demand for preventive caries protocol with lasers in orthodontics [20, 25] and the possibility to optically evaluate the changes during the procedures. The 20% of the patients with high caries risk due to genetic factors have an indication to intensified traditional prevention and immunostimulatory therapeutics [1]. However, it could result in fluorosis or other systemic compromises, which could be mitigated by the laser application.

The statistical similarity between direct and indirect bracket bonding [14, 26] led the present study to choose the simplicity

Table 2 Measurements description of shear bond strength of groups (MPa)

Groups	Minimum	Mean (± SD)	Median	Maximum	CI
G1—Control	6.22	11.61 (± 5.79)^{a,b}	9.76	20.07	(8.73; 14.49)
G2—Nd:YAG	4.60	7.82 (± 4.32)^{a,b}	7.01	14.16	(5.32; 10.31)
G3—Nd:YAG + Al_2O_3	4.41	15.36 (± 7.17)^{a}	13.31	26.19	(11.23; 19.50)
G4—Al_2O_3	10.71	13.23 (± 5.26)^{a,b}	11.36	24.21	(10.20; 16.27)
G5—Al_2O_3 + Nd:YAG	10.83	16.20 (± 6.68)^{a}	14.15	28.20	(12.34; 20.05)

SD standard deviation. ANOVA and post hoc Tukey tests. *CI* 95% of confidence interval of the mean

^{a,b} intergroup statistical significance

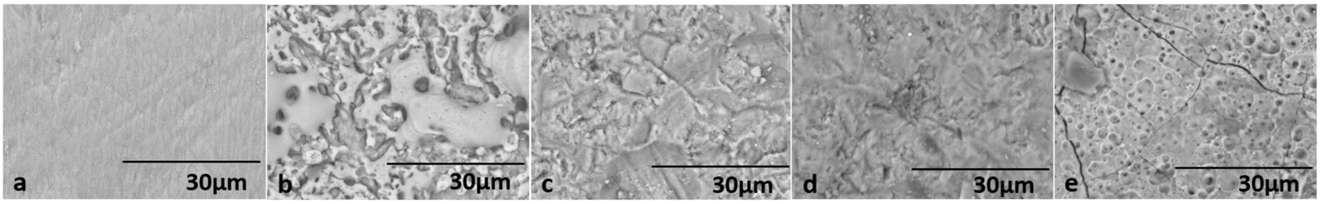

Fig. 2 SEM images after preconditioning (T1) of enamel surface: **a** G1 initial control; **b** G2 after Nd:YAG laser irradiation; **c** G3 after laser irradiation + Al_2O_3; **d** G4 after Al_2O_3; **e** G5 after Al_2O_3 + Nd:YAG laser irradiation

of the direct technique. Regarding the use of bovine instead of human teeth, it is known that the bovine incisor teeth have chemical and microstructural similarities with human tooth becoming adequate for enamel adhesion studies, as reported in [22, 27, 28]. Most important for the present work, the authors of ref. [27] have shown that there is no statistically significant difference between SBS values between bovine and human teeth. Besides, the use of human premolars would demand resin compensations to adapt to the utilized bracket, compromising the specimen standardization.

The present SBS results agree with a meta-analysis which shows values ranging from 3.5 to 27.8 MPa (mean, 13.4 MPa; SD, 5.7) [29]. Furthermore, based on the minimal adhesive resistance for clinical demand on orthodontics treatments—5.9 to 7.8 MPa [21]—all the groups of this study presented favorable results. Additionally, our results agree with those of

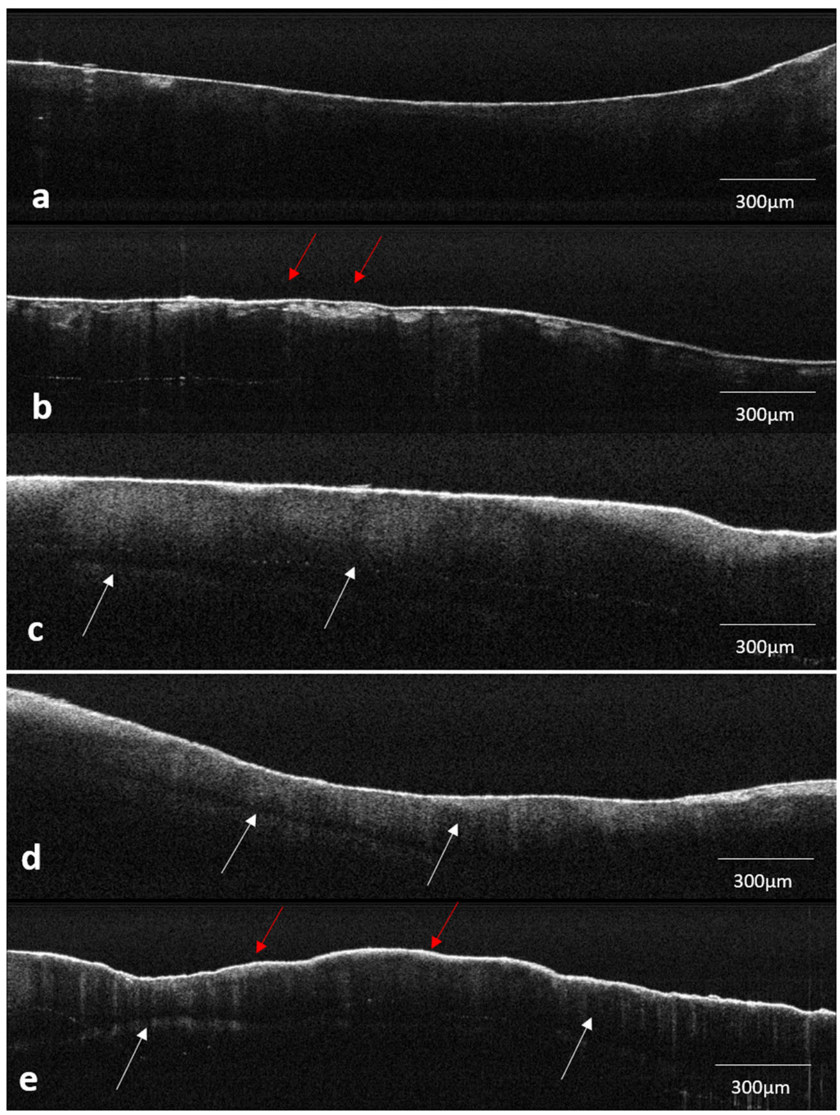

Fig. 3 OCT images after preconditioning (T1) of enamel surface: **a** G1 initial control; **b** G2 after Nd:YAG laser irradiation; **c** G3 after laser irradiation + Al_2O_3; d G4 after Al_2O_3; e G5 after Al_2O_3 + Nd:YAG laser irradiation. On OCT images, the laser effect is shown by dotted arrows and sandblasting effect by white arrows

Table 3 Measurements variation of α before and after pretreatment on enamel surface

Groups	Δ (± SE) (μm^{-1})	*p*-Value of Δ
G2—Nd:YAG	1.04 (± 0.37)[a] (↑)	0.0062
G3—Nd:YAG + Al_2O_3	− 0.67 (± 0.52)[a,b] (↓)	< 0.0001
G4—Al_2O_3	0.92 (± 0.48)[a] (↑)	0.0637
G5—Al_2O_3 + Nd:YAG	− 2.57 (± 1.13)[b] (↓)	0.1893

SE standard error. Kruskal Wallis and post hoc *Dunn* tests. Δ is a variation of α before and after pretreatment

[a,b] intergroup statistical significance

Sfondrini et al. [30] of SBS—between 16.74 ± 5.18 MPa—using the same lingual brackets in similar tests conditions of sandblasting procedure associated to H_3PO_4, but on the buccal enamel. The present study also agrees with other results that considered questionable the association of sandblasting and H_3PO_4 for increase lingual bracket bonding protocol [31].

It is important to note that the reporting of SBS inherently assumes a uniform interfacial shear stress, whereas the actual situation involves stress concentrations both at the loading platen (chisel) and at local microstructural irregularities, in this study either in the literature.

The sandblasting improves the micro-retention after etching because the aluminum oxide particles (50 μm of diameter) by randomly conditioning the enamel prisms (5 μm of diameter), providing a surface without debris or plaque [32], and removing different parts of the surface [33], consequently increasing the SBS values. It exposes the subjacent prismatic structure [34] and increases the superficial roughness. The etching does an additional demineralization of the enamel structure, enhancing the area of surface contact [34]. It consequently increases the union strength. Morphologically, this alteration appears as large structural disorganization of enamel prisms in the SEM images—especially when Al_2O_3 was the final step (G3 and G4- Fig. 2c and d)—and, in the OCT analysis (Fig. 3c and d), as an increase in depth penetration compared to the other protocols (Figs. a, b and e).

The chemical and morphological alterations on the enamel after lasing by Nd:YAG changed the balance of Ca/P in 10 to 20 μm in depth according to the temperatures reached. Between 100 °C and 650 °C, the hydroxyapatite presents an expansion of their unit mesh. Until 1100 °C there is a continuous expansion of hydroxyapatite crystallite sizes and tricalcium phosphate formation (β-TCP). Above 1100 °C, the β-TCP phase is converted into α-TCP. It allows the hydroxyapatite melting (at 1280 °C) creating a new phase (tetracalcium diphosphate). These matrix crystallographic alterations reduce the water permeability and carbonate amount and enhance the hydroxyapatite crystal sizes. It indicates an additional resistance to acid contents that help to prevent dental caries [35, 36], because it decreases the critical pH for irradiated enamel tissue.

The melted enamel could increase the adhesive mechanical bonding [37, 38] once the surface alterations were similar to micro-craters—on tested output—as seen in the microscopical analysis (Fig. 2b) [37]. The melting effect is seeing as dense points on enamel superficial line in OCT images (Fig. 2b).

The results of the preconditioning association groups (G3 and G5; Fig. 3 c and e) are new in the literature, to the best of our knowledge. It is speculated that the subsequent treatment of Nd:YAG laser further increased the contact surface of the sandblasted enamel and simultaneously eliminated the weak structures caused by the sandblasting. The Al_2O_3 removes partially the melting effect (G3), and the laser irradiation is effective even on disorganized surfaces (G5). It also implies that the protective laser effect could be active without harm the SBS. Furthermore, considering the SBS, the present results demonstrated no differences in the pretreatment protocols tested. It corroborates with other studies that showed no difference to the traditional protocol [11, 39–43].

Beer's law relates the light attenuation through the material properties with its traveled distance. Different biological tissues, or states of a tissue (healthy or diseased), present different optical attenuation coefficients (α). Several studies have reported the behavior of the attenuation coefficient α carried out between healthy and demineralized enamel [24, 34, 44–46]. Differently, the present study proposed to identify the attenuation coefficient differences due to different types of preconditioning.

The higher is the α, the less is the light transmission [24, 46], due to light scattering and absorption. In the laser (Fig. 3b) and Al_2O_3 (Fig. 3d) groups, the final surface promoted a higher light scattering. It was possible due to a higher density (in the case of the laser), or with great structural disorganization (in the case of sandblasting) [46]. It increases the light reflection on the surface and reduces the light propagation within the specimen.

After preconditioning, the associated groups (G3 and G5) presented a decrease in the α. This fact indicates greater light transmission in these images and low interaction with scattering centers [45], probably due to the lower mineral content on enamel sandblasted by Al_2O_3 particles that removes the central enamel [34]. The values of α were similar for both preconditioning orders presented.

The study limitation was the relatively large variations in the individual SBS values within the different sample groups because of the substrate heterogeneity. For better standardization, 2 mm of incisal surface was removed from all teeth, to allow the chisel work without obstacles, and the device for specimen inclusion was used to standardize the angle of the chisel and the interfacial shear bond. Additionally, care was taken with the sample calculation, supported by literature. Further research in this area should exploit the OCT for in vivo images of lingual brackets region in human teeth, looking for WLS and caries development.

Conclusions

All protocols employed in this work, using lasers and conventional ways, led to SBS within the recommended values in the literature. The irradiation with Nd:YAG laser and/or aluminum oxide sandblasting presented enamel structural modifications that maintains the clinical adhesive performance.

Sandblasting preconditioning did not increase significantly the SBS in bonding protocols and mechanically reduces the laser melting effect.

Authors' contributions Mônica Schaffer Lopes contributed the idea, hypothesis, and experimental design; performed the experiments in partial fulfillment of requirements for a degree; performed a certain test; wrote the manuscript; and contributed substantially to discussion. Daísa Lima Pereira contributed the experimental design, consulted on and performed statistical evaluation, and contributed substantially to discussion. Cláudia Cristina Brainer de Oliveira Mota proofread the manuscript and contributed substantially to discussion. Marcello Magri Amaral developed the custom software for analysis, performed a certain test, and contributed substantially to discussion. Denise Maria Zezell conceived the experiment, provided infrastructure, proofread the manuscript, and contributed substantially to discussion. Anderson Stevens Leonidas Gomes conceived the experiment, provided infrastructure, proofread the manuscript, and contributed substantially to discussion.

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Compliance with ethical standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical approval This ex vivo study was exempted from the evaluation by the Ethical Committee on Animal Experiments (Universidade de São Paulo) under process number 107/12, since it used bovine teeth collected in accredited slaughterhouse.

Informed consent For this type of study, formal consent is not required.

References

1. Strömberg N, Esberg A, Sheng N, Mårell L, Löfgren-Burström A, Danielsson K, Källestål C (2017) Genetic- and lifestyle-dependent dental caries sefined by the acidic proline-rich protein genes PRH1 and PRH2. EBioMedicine 26:38–46. https://doi.org/10.1016/j.ebiom.2017.11.019
2. Sagarika N, Suchindran S, Loganathan S, Gopikrishna V (2012) Prevalence of white spot lesion in a section of Indian population undergoing fixed orthodontic treatment: an in vivo assessment using the visual International Caries Detection and Assessment System II criteria. J Conserv Dent 15:104–108. https://doi.org/10.4103/0972-0707.94572
3. Livas C, Kuijpers-Jagtman AM, Bronkhorst E, Derks A, Katsaros C (2008) Quantification of white spot lesions around orthodontic brackets with image analysis. Angle Orthod 78:585–590. https://doi.org/10.2319/0003-3219(2008)078[0585:QOWSLA]2.0.CO;2
4. Listl S, Galloway J, Mossey PA, Marcenes W (2015) Global economic impact of dental diseases. J Dent Res 94:1355–1361. https://doi.org/10.1177/0022034515602879
5. Demling A, Demling C, Schwestka-Polly R, Stiesch M, Heuer W (2010) Short-term influence of lingual orthodontic therapy on microbial parameters and periodontal status a preliminary study. Angle Orthod 80:480–484. https://doi.org/10.2319/061109-330.1
6. van der Veen MH, Attin R, Schwestka-Polly R, Wiechmann D (2010) Caries outcomes after orthodontic treatment with fixed appliances: do lingual brackets make a difference? Eur J Oral Sci. 118:298–303. https://doi.org/10.1111/j.1600-0722.2010.00733.x
7. Wiechmann D, Klang E, Helms HJ, Knösel M (2015) Lingual appliances reduce the incidence of white spot lesions during orthodontic multibracket treatment. Am J Orthod Dentofacial Orthop 148:414–422. https://doi.org/10.1016/j.ajodo.2015.05.015
8. Lombardo L, Ortan YÖ, Gorgun Ö, Panza C, Scuzzo G, Siciliani G (2013) Changes in the oral environment after placement of lingual and labial orthodontic appliances. Prog Orthod 14:28–35. https://doi.org/10.1186/2196-1042-14-28
9. Brokos Y, Stavridakis M, Bortolotto T, Krejci I (2015) Evaluation of enamel thickness of upper anterior teeth in different age groups by dental cone beam computed tomography scan in vivo. IJACR 2:1396–409
10. Ward P (2013) Bonding techniques in lingual orthodontics. J Orthod 40:s20–s26. https://doi.org/10.1179/1465313313Y.0000000060
11. Halpern RM, Rouleau T (2010) The effect of air abrasion preparation on the shear bond strength of an orthodontic bracket bonded to enamel. Eur J Orthod 32:224–227. https://doi.org/10.1093/ejo/cjp080
12. Bayram M, Yesilyurt C, Kusgöz A, Ulker M, Nur M (2011) Shear bond strength of orthodontic brackets to aged resin composite surfaces: effect of surface conditioning. Eur J Orthod 33:174–179. https://doi.org/10.1093/ejo/cjq048
13. Mati M, Amm E, Bouserhal J, Bassil-Nassif N (2012) Effet du microsablage de l'émail vestibulaire et lingual sur la résistance au cisaillement d'attaches orthodontiques collées avec un primaire automordançant. Int Orthod 10:422–431. https://doi.org/10.1016/j.ortho.2012.09.008
14. Lombardo L, Kaplan A, Lapenta R, Bratti E, Pera C, Scuzzo G, Siciliani G (2011) A comparative study of lingual bracket bond strength. Orthodontics 12:178–187
15. Suma S, Anita G, Chandra Shekar B, Kallury A (2012) The effect of air abrasion on the retention of metallic brackets bonded to fluorosed enamel surface. Indian J Dent Res 23:230–235. https://doi.org/10.4103/0970-9290.100432
16. Hamdan WA, Badri S, El Sayed A (2018) The effect of fluoride varnish in preventing enamel demineralization around and under orthodontic bracket. Int Orthod 16:1–11. https://doi.org/10.1016/j.ortho.2018.01.005
17. Nascimento PL d MM, Fernandes MTG, de Figueiredo FED, Faria-e-Silva AL (2016) Fluoride-releasing materials to prevent white spot lesions around orthodontic brackets: a systematic review. Braz Dent J 27:101–107. https://doi.org/10.1590/0103-6440201600482
18. Braga SRM, de Oliveira E, Sobral MAP (2017) Effect of neodymium:yttrium-aluminum-garnet laser and fluoride on the acid demineralization of enamel. J Investig Clin Dent 8:1–6. https://doi.org/10.1111/jicd.12185
19. Seino PY, Freitas PM, Marques MM, de Souza Almeida FC, Botta SB, Moreira MSNA (2015) Influence of CO2 (10.6 μm) and Nd:YAG laser irradiation on the prevention of enamel caries around orthodontic brackets. Lasers Med Sci 30:611–616. https://doi.org/10.1007/s10103-013-1380-8

20. Zezell DM, Boari HGD, Ana PA, Eduardo CDP, Powell GL (2009) Nd:YAG laser in caries prevention: a clinical trial. Lasers Surg Med 41:31–35. https://doi.org/10.1002/lsm.20738
21. Reynolds IR (1975) A review of direct orthodontic bonding. Br J Orthod 2:171–178. https://doi.org/10.1080/0301228X.1975.11743666
22. Larry J, Oesterle LJ, Shellhart WC, Gary K, Belanger G (1998) The use of bovine enamel in bonding studies. Am J Orthod Dentofacial Orthop 114:514–519. https://doi.org/10.1016/s0889-5406(98)70171-4
23. Eng J (2003) Sample size estimation: how many individuals should be studied? Radiology 227:309–313. https://doi.org/10.1148/radiol.2272012051
24. Cara ACB, Zezell DM, Ana PA, Maldonado EP, Freitas AZ (2014) Evaluation of two quantitative analysis methods of optical coherence tomography for detection of enamel demineralization and comparison with microhardness. Lasers Surg Med 46:666–671. https://doi.org/10.1002/lsm.22292
25. Boari HGD, Ana PA, Eduardo CP, Powell GL, Zezell DM (2009) Absorption and thermal study of dental enamel when irradiated with Nd:YAG laser with the aim of caries prevention. Laser Phys 19:1463–1469. https://doi.org/10.1134/S1054660X09070160
26. Shpack N, Geron S, Floris I, Davidovitch M, Brosh T, Vardimon AD (2007) Bracket placement in lingual vs labial systems and direct vs indirect bonding. Angle Orthod 77:509–517. https://doi.org/10.2319/0003-3219(2007)077[0509:BPILVL]2.0.CO;2
27. Nakamichi I, Iwaku M, Fusayama T (1983) Bovine teeth as possible substitutes in the adhesion test. J Dent Res 62:1076–1081. https://doi.org/10.1177/00220345830620101501
28. Carvalho MFF, Leijôto-Lannes ACN, Rodrigues MCN d S, Nogueira LC, Ferraz NKL, Moreira AN et al (2018) Viability of bovine teeth as a substrate in bond strength tests: a systematic review and meta-analysis. J Adhes Dent 20:471–479. https://doi.org/10.3290/j.jad.a41636
29. Finnema KJ, Özcan M, Post WJ, Ren Y, Dijkstra PU (2010) In-vitro orthodontic bond strength testing: a systematic review and meta-analysis. Am J Orthod Dentofac Orthop 137:615–622. https://doi.org/10.1016/j.ajodo.2009.12.021
30. Sfondrini MF, Gandini P, Gioiella A, Zhou FX, Scribante A (2017) Orthodontic metallic lingual brackets: the dark side of the moon of bond mailures? J Funct Biomater 8:27–34. https://doi.org/10.3390/jfb8030027
31. Daratsianos N, Schütz B, Reimann S, Weber A, Papageorgiou SN, Jäger A, Bouraue C (2019) The influence of enamel sandblasting on the shear bond strength and fractography of the bracket adhesive-enamel complex tested in vitro by the DIN 13990:2017-04 standard. Clin Oral Investig 23:2975–2985. https://doi.org/10.1007/s00784-018-2692-7
32. Reicheneder C, Hofrichter B, Faltermeier A, Proff P, Lippold C, Kirschneck C (2014) Shear bond strength of different retainer wires and bonding adhesives in consideration of the pretreatment process. Head Face Med 10:51. https://doi.org/10.1186/1746-160X-10-51
33. Robles-Ruíz JJ, Arana-Chavez VE, Ciamponi AL, Abrão J, Kanashiro LK (2015) Effects of sandblasting before orthophosphoric acid etching on lingual enamel: in-vitro roughness assessment. Am J Orthod Dentofacial Orthop 147:S76–S81. https://doi.org/10.1016/j.ajodo.2014.11.023
34. Patcas R, Zinelis S, Eliades G, Eliades T (2015) Surface and interfacial analysis of sandblasted and acid-etched enamel for bonding orthodontic adhesives. Am J Orthod Dentofacial Orthop 147:S64–S75. https://doi.org/10.1016/j.ajodo.2015.01.014
35. Ana PA, Bachmann L, Zezell DM (2006) Lasers effects on enamel for caries prevention. *Laser Phys* 16:865–875. https://doi.org/10.1134/S1054660X06050197
36. Zezell DM, Ana PA, Benetti C, Goulart VP, Bachmann L, Tabchoury CPM, et al (2010) Compositional and crystallographic changes on enamel when irradiated by Nd:YAG or Er,Cr:YSGG lasers and its resistance to demineralization when associated with fluoride. Proc SPIE 7549, Laser Dent XVI 7549:75490G. https://doi.org/10.1117/12.842967
37. Wen X, Zhang L, Liu R, Deng M, Wang Y, Liu L, Nie X (2014) Effects of pulsed Nd:YAG Laser on tensile bond strength and caries resistance of human enamel. Oper Dent 39:273–282. https://doi.org/10.2341/12-416-L
38. Banda NR, Reddy GV, Shashikiran ND (2011) Evaluation of primary tooth enamel surface morphology and microhardness after Nd: YAG laser irradiation and APF gel treatment-an in vitro study. Int J Clin Pediatr Dent 35:377–382. https://doi.org/10.17796/jcpd.35.4.8550556gp6r5xt6t
39. Borsatto MC, Catirse ABEB, Palma Dibb RG, Nascimento TN, Rocha RASS, Corona SAM (2002) Shear bond strength of enamel surface treated with air-abrasive system. Braz Dent J 13:175–178. https://doi.org/10.1590/S0103-64402002000300006
40. Cal-Neto JP, Castro S, Moura PM, Ribeiro D, Miguel JAM (2011) Influence of enamel sandblasting prior to etching on shear bond strength of indirectly bonded lingual appliances. Angle Orthod 81:149–152. https://doi.org/10.2319/050210-237.1
41. Robles-Ruíz JJ, Ciamponi AL, Medeiros IS, Kanashiro LK (2014) Effect of lingual enamel sandblasting with aluminum oxide of different particle sizes in combination with phosphoric acid etching on indirect bonding of lingual brackets. Angle Orthod 84:1068–1073. https://doi.org/10.2319/120613-897.1
42. Zarif Najafi H, Moshkelgosha V, Khanchemehr A, Alizade A, Mokhtar A (2015) The effect of four surface treatment methods on the shear bond strength of metallic brackets to the fluorosed enamel. J Dent (Shiraz) 16:251–259
43. Baumgartner S, Koletsi D, Verna C, Eliades T (2017) The effect of enamel sandblasting on enhancing bond strength of orthodontic brackets : a systematic review. J Adhes Dent 19:463–473. https://doi.org/10.3290/j.jad.a39279
44. Maia AMA, De Freitas AZ, Campello SDL, Gomes ASL, Karlsson L (2016) Evaluation of dental enamel caries assessment using quantitative light induced fluorescence and optical coherence tomography. J Biophotonics 9:596–602. https://doi.org/10.1002/jbio.201500111
45. Popescu DP, Sowa MG, Hewko MD, Choo-Smith L-P (2008) Assessment of early demineralization in teeth using the signal attenuation in optical coherence tomography images. J Biomed Opt 13:054053. https://doi.org/10.1117/1.2992129
46. Sowa MG, Popescu DP, Friesen JR, Hewko MD, Choo-Smith LP (2011) A comparison of methods using optical coherence tomography to detect demineralized regions in teeth. J Biophoton 4:814–823. https://doi.org/10.1002/jbio.201100014