MEANDROS MEDICAL AND DENTAL JOURNAL
June 2024 25(2):97-108

Meandros Medical and Dental Journal
doi: 10.69601/meandrosmdj.1523793

Research Article

IMPACT OF ER, CR: YSGG LASER DEBONDING ON THE MECHANICAL PROPERTIES OF AGED AND NON-AGED LITHIUM DISILICATE CERAMICS

Damla GÜNEŞ ÜNLÜ [1], Pınar YILDIZ [2*], Nazire Nurdan ÇAKIR KILINÇ [3]

[1] Department of Prosthodontics, Faculty of Dentistry, Nuh Naci Yazgan University, Kayseri, TURKEY
[2] Nimet Bayraktar Oral and Dental Health Center, Kayseri, TURKEY
[3] Department of Restorative Dentistry, Faculty of Dentistry, Nuh Naci Yazgan University, Kayseri, TURKEY
*Correspondence: dentistpinar@hotmail.com

ABSTRACT

Objective: The aim of this study is to evaluate the effects of Er,Cr:YSGG laser debonding on the mechanical properties of aged and non-aged lithium disilicate ceramics.

Materials and Methods: A total of 36 lithium disilicate samples with dimensions of 14x4x1 mm were prepared. Half of the samples underwent 5000 thermal cycles to simulate artificial aging. The aged and non-aged samples were divided into two subgroups: one subgroup was designated as the control group and did not receive laser treatment, while the other subgroup was treated with Er, Cr:YSGG laser for debonding (n=9). The flexural strength and modulus of the lithium disilicate samples were assessed using three-point bending tests before and after artificial aging. The surface roughness of a sample that did not undergo the three-point bending test was measured with AFM, its microhardness was assessed using the Vickers hardness test, and surface morphology was examined with FESEM. Two-way ANOVA and Bonferroni correction to determine the significance of the results were used for statistical analysis.

Results: The results indicated that aging significantly reduced the flexural strength (p=0.031), however, laser debonding did not have a significant effect on the flexural strength or elastic modulus of either aged or non-aged samples. Aged groups had higher roughness. No fractures or microcracks were observed in any group in FESEM analysis.

Conclusion: Laser debonding effectively removes lithium disilicate restorations without compromising their mechanical properties, supporting their reuse in clinical practice. It is important to note that aging reduces the flexural strength of lithium disilicate ceramics.

Keywords: Artificial aging, Er, Cr:YSGG laser, flexural strength, lithium disilicate

Received: 28 July 2024
Revised: 15 August 2024
Accepted: 16 August 2024
Published: 31 August 2024

INTRODUCTION

The biocompatibility, durability, and aesthetic appeal of all-ceramic restorations have made them popular in recent years (1). Failure to position an aesthetic restoration during cementation may occur and the restoration may require immediate debonding. Furthermore, during their use, they may require removal due to external damage, caries, marginal integrity problems, microleakage, or the need for endodontic treatment (2). However, since all-ceramic restorations are often cemented with adhesive cement, debonding them is time-consuming and difficult (3). The traditional method for removing ceramic restorations involves sectioning the material using rotary tools and burs made of diamond or tungsten carbide. This conventional removal technique compromises the integrity of the restoration and is inconvenient. Additionally, the prolonged extraction process may cause damage to the underlying natural tooth (4,5).

Lasers can be used for many purposes in dentistry (6-8), and have been investigated as a potential alternative technique, particularly for the removal of ceramic appliances from natural teeth (2-5). Erbium lasers may especially absorb water molecules and excess monomers in luting cement, penetrating all ceramic materials. This absorption causes the cement to debond and these molecules to evaporate (2).

In a study, enamel was evaluated after debonding with the Er,Cr:YSGG laser and concluded that the Er,Cr:YSGG laser is effective in debonding the restorations without causing harmful effects on the enamel (9). In addition, previous studies (10-13) using SEM analysis after debonding with an Er,Cr:YSGG laser found no major irregularities or cracks in lithium disilicate ceramics. Since no fractures occurred in the restorations during the process, it was concluded that the restorations could be reused. However, surface roughness and surface hardness were not investigated.

Although studies (10-13) have shown that all-ceramic prostheses removed with Er,Cr:YSGG lasers can be reused, the literature does not indicate how the mechanical properties of lithium disilicate ceramics are affected by laser application. Additionally, it is unclear how laser treatment impacts lithium disilicate ceramics after late-stage debonding. The aim of this study was to evaluate the effects of Er,Cr:YSGG laser debonding on the mechanical properties of both aged and nonaged lithium disilicate ceramics. This study hypothesizes that the Er,Cr:YSGG laser debonding process does not significantly affect the flexural strength (FS) and flexural modulus (FM) of both artificial aged and non-aged lithium disilicate ceramics.

MATERIALS AND METHODS

This study investigates the effect of laser treatment on lithium disilicate ceramics using a three-point bending test, conducted both before and after artificial aging. The sample size for the in vitro study was determined using Minitab software (Minitab 22, Minitab LLC, State College, PA), aiming for statistical power (beta) of 0.90 and a significance level (alpha) of 0.05, based on data from a previous study (7). The analysis indicated that a three-point bending test should be conducted with eight samples for each of four study groups. Additionally, one extra sample per group was prepared for other analyses, resulting in a total of nine samples per group.

Preparation of lithium disilicate samples

Samples, each 1 mm thick, were cut from pre-crystallized lithium disilicate blocks (IPS e.max CAD, Ivoclar Vivadent, Schaan Liechtenstein) using a precision cutting tool. These samples were then divided into three parts, creating samples with dimensions of 14x4x1 mm (n=36). To achieve the final strength and aesthetic qualities, the pre-crystallized samples were subjected to the crystallization process in a ceramic furnace (Programat EP 510, Ivoclar Vivadent). After crystallization, the samples were cooled to room temperature. The specimens were then polished using a cotton buffing wheel brush, and a fine layer of glazing material was applied with a smooth brush. Finally, the samples were fired on a furnace tray in accordance with the manufacturer's instructions.

Half of the samples were subjected to 5000 thermal cycles (thermocycler, SD Mechatronik Thermocycler, Westerham, Germany with a dwell time of 30 s. 5000 cycles of artificial aging correspond to 6 months in in-vivo conditions.

The aged and non-aged samples were divided into two subgroups. The samples in the first subgroup received no treatment, while the samples in the second subgroup were subjected to Er,Cr:YSGG laser treatment. Details of all groups are provided in Table 1.

In this study, an Er,Cr:YSGG laser with a wavelength of 2870 nm was used. The laser was applied for 10 seconds at a power setting of 3.5 watts and a repetition rate of 10 Hz, utilizing an MZ6 quartz application tip with a diameter of 600 µm. Laser treatment were applied to the lithium disilicate samples from a non-contact distance of 1 mm. The scanning method employed involved horizontal sweeping motions perpendicular to the surface (14).

Table 1. Study groups

Groups	Subgroups	Group name	N
Non-aged	No laser applicated	NANL	9
	Laser applicated	NAL	9
Aged	No laser applicated	ANL	9
	Laser applicated	AL	9

Flexural strength and flexural modulus test

One sample from each group was not subjected to mechanical test and was reserved for other analyses (AFM analysis, Vickers microhardness test and FESEM analysis). To assess flexural strength (σ), which represents the stress experienced by the material just before failure, and flexural modulus (E), which is the ratio of stress to strain during flexural deformation, the ceramics underwent a three-point bending test. FS was assessed using a universal testing machine (AG-X 50kN, Shimadzu, Kyoto, Japan) with a conventional three-point bending test (Figure 1). Each specimen was placed with a 12 mm span between two supporting fixtures. A downward load was applied at a crosshead speed of 1 mm/min until the specimen failed.

The following formulas were used: F represents the maximum load (N), L is the distance between supports (12 mm), w is the sample width, h is the sample thickness, and d in the second equation represents the average deviation of the linear section's overall slope. All these measurements were taken in millimetres using a digital caliper before the test. The Figure 1. displays the test diagram along with the definitions of these symbols.

$$Flexural\ \ Strength\ \ (\sigma) = 3FL/wh^2$$
$$Flexural\ \ Modulus\ \ (E) = L^3F/4wh^3d$$

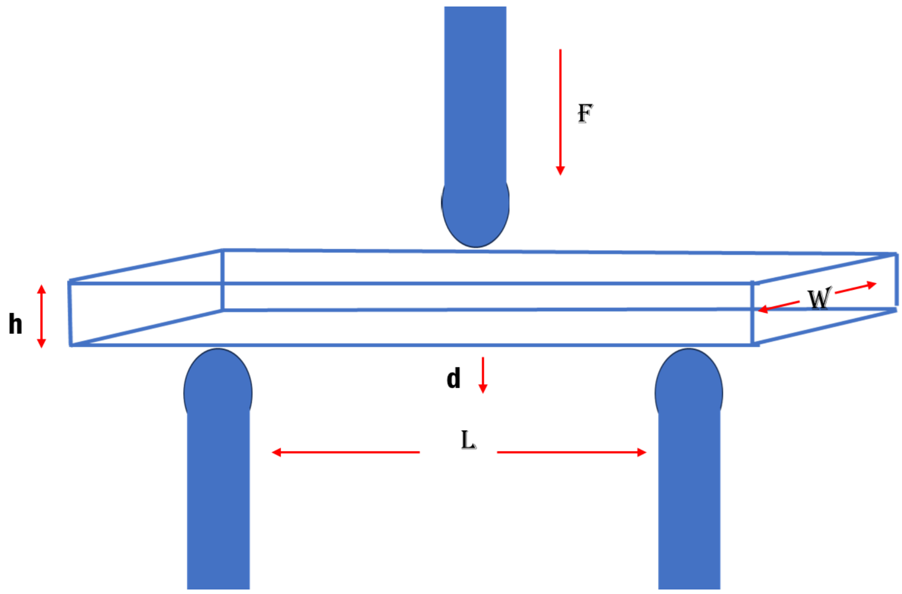

Figure 1. Diagram of the test design and definitions of the symbol of the formulas

AFM (atomic force microscopy) analysis

The surface topography was analyzed with an AFM. The surface roughness was measured 3 times for each test group specimen by using an AFM (MultiMode VIII, Veeco Instruments, Plainview, USA) in non-contact mode. The scan sizes were 10×10 mm, and the scan rate was 1,001 Hz.

Vickers microhardness test

Vickers hardness test was conducted on one sample from each group using a microhardness tester (EMCO Test Dura-scanKuchl, Austria) equipped with a diamond indenter. The tests were performed for 15 seconds at a force of 2.94 N. After measuring the indentation diagonals, the results were expressed in Vickers hardness units. The average of the three measured values was calculated and reported.

FESEM (field emission scanning electron microscopy) analysis

One specimen from each test group was placed on a metallic stub, coated with gold (Quorum Q150 RES, UK), and examined at a magnification of 2000x using a field emission scanning electron microscopy (Zeiss Gemini 500, Carl Zeiss, Oberkochen, Germany) to assess the surface morphology.

Statistical analysis

The data for FS and FM were confirmed to have a normal distribution and consistent homogeneity of variance using the Shapiro-Wilk and Levene tests. Two-way ANOVA and Bonferroni correction tests were used to analyze the data. (p=0.05, 95% confidence interval).

RESULTS

According to the results of the Two-way ANOVA test, the FS of lithium disilicate samples was significantly affected by aging, but was not significantly influenced by laser application or the interaction between these two factors (Table 2). Additionally, samples that underwent aging had lower FS. According to the results of the Two-Way ANOVA test, the FM of lithium disilicate samples was not significantly affected by aging, laser application, or their interaction (Table 3).

Table 2. Mean ± standard deviations of FS data (N) and Two-way ANOVA results

Process	**Artificial Aging**	
	Aged ($\underline{x}$±sd)	Non-aged ($\underline{x}$±sd)
No Laser applicated	422.50±99.01	498.50±94.38
Laser applicated	453.78±105.51	527.46±69.30
*Aging effect: F=5.174 p=0.031 Laser effect: F=0.838 p=0.368 Aging * Laser effect: F=0.001 p=0.972*		

x̄=mean, sd=standard deviations

Table 3. Mean ± standard deviations of FM data and Two-way ANOVA results

Process	Artificial Aging	
	Aged (x̄±sd)	Non-aged (x̄±sd)
No Laser applicated	65.32±6.88	66.26±7.26
Laser applicated	69.26±7.04	66.99±7.70
Aging effect: F=0.068 p=0.796 Laser effect: F=0.833 p=0.369		
Aging * Laser effect: F=0.392 p=0.536		

x̄=mean, sd=standard deviations

AFM results

Representative AFM images of all groups are presented in Figure 2. The grain boundaries, where the grains are regularly distributed, were visible in the NANL group, with a Ra value of 3.25. In the NAL group, the grains were more irregularly distributed, with a Ra value of 10.88. The Ra values for the AL and ANL groups were 15.11 and 15.54, respectively.

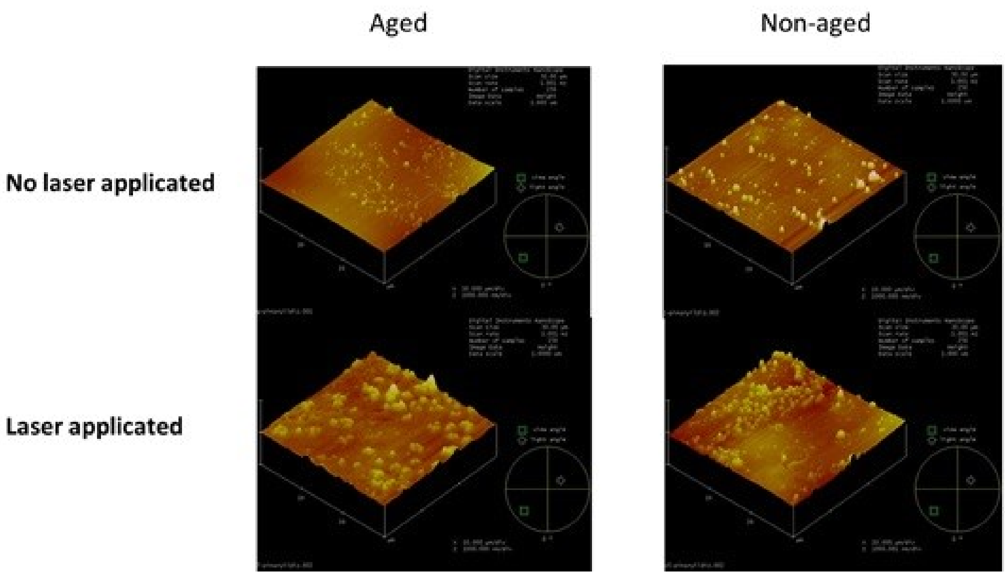

Figure 2. Representative AFM images of all groups

Vickers microhardness test results

The Vickers microhardness test results and mean values are shown in Table 4. The AL group exhibited lower average microhardness values compared to the other groups. The remaining groups showed comparable outcomes.

Table 4. Vickers microhardness measurement results and mean values

	1	2	3	Mean
NANL	627	630	603	620
NAL	625	619	630	624.66
ANL	633	627	625	628.33
AL	596	593	598	595.66

FESEM results

Figure 3 represents the 2000x FESEM images of all groups. The FESEM studies did not reveal microfractures, microcracks, or fractures in any group. As expected, the laser-applied groups showed ablation craters.

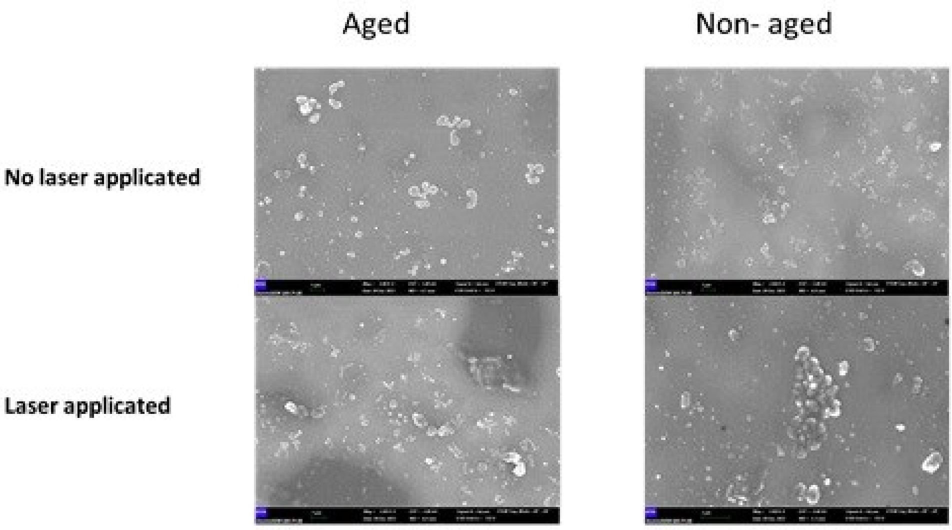

Figure 3. The 2000x FESEM images of all groups

DISCUSSION

Immediate removal of restorations may be necessary in cases of malposition during the cementation process. However, it is more common to observe the need for restoration removal after a period of use, due to factors such as secondary caries, discoloration resulting from microleakage, the necessity for additional endodontic treatment, and sensitivity (2). The capacity to reuse the restoration under such circumstances offers a substantial advantage in terms of both time and cost efficiency. Previous studies have conducted mechanical tests to determine the feasibility of reusing materials after laser debonding with Er:YAG laser (8,15). However, to the best of the author's knowledge no study in the literature has investigated the effect of Er,Cr:YSGG lasers on the FS of lithium disilicate ceramics, nor has any study evaluated the mechanical properties of aged samples following laser debonding. Therefore, this study aimed to evaluate the changes in the mechanical properties of both aged and non-aged lithium disilicate ceramics after debonding with an Er,Cr:YSGG laser. The results indicate that aging significantly reduces the FS of lithium disilicate ceramics. However, laser debonding treatment did not have a significant impact on the FS of the lithium disilicate ceramics material. Additionally, the FM of lithium disilicate ceramics was not significantly affected by either aging or laser debonding. Therefore, the null hypothesis of the study was partially accepted.

Since ceramics are more brittle in tension than in compression, FS is a critical property for evaluating their resistance to deformation (16). It is also essential to determine the maximum force required to fracture a specimen of a given length (17). FS is commonly measured using three-point bending, four-point bending, and biaxial flexural tests, as outlined in ISO 6872 for dental ceramic materials. According to a literature (18) the dental researchers prefer the three-point bending test. This study evaluated the effect of laser debonding on the mechanical properties of aged and non-aged lithium disilicate ceramics using the three-point bending test. FS and FM values were then calculated based on the test results.

Aging is a natural degradation process that affects the chemical and mechanical properties of materials over time. Long-term use in oral environment tests a material's ability to withstand stress. Assessing the FS of ceramic materials immediately after sintering limits our understanding of their clinical performance. Aging is critical to assessing durability, and thermocycling is commonly used in studies to simulate long-term aging (19). This process accelerates material fatigue and degradation, potentially leading to failure. A previous study (13) demonstrated that there was no significant difference between a 5000-cycle thermocycling application and a 30000-cycle thermocycling application in terms of their effects on aging and that aging reduced the debonding time with Er:CR;YSGG laser. Consequently, this study applied a 5000-cycle artificial aging process.

While some studies confirm that aging affects the FS of ceramic materials, its effect on lithium disilicate ceramics is still debated (20-22). While some researchers (20,21) have found that aging does not affect the FS of lithium disilicate ceramics, other researchers have reported that artificial aging reduces the FS of these ceramics (22). The result of this study suggests that aging reduces the FS of the ceramics, regardless of laser application.

Pulse energy (J) is computed as average power (W) divided by pulse repetition rate (Hz). Higher average power levels result in greater pulse energies, which assist in approaching the ablation thresholds of bonding cement, thus facilitating a speedier debonding process (13). The current investigation used a low pulse repetition rate and high average power following this equation. In particular, the Er,Cr:YSGG laser was run for 10 seconds at 3.5 W and 10 Hz at a distance of 1 mm. The primary objective of this study was to evaluate the changes in the mechanical properties of lithium disilicate ceramics material, after Er:Cr:YSGG laser debonding treatment, without the influence of cementation. To isolate the effects of the laser treatment, the ceramic samples were not bonded to dental tissue in any of the groups.

Birand and Kurtulmuş Yılmaz (23) employed Er,Cr:YSGG lasers for the removal of zirconia crowns from titanium implant abutments and assessed the fracture resistance of the ceramics. They concluded that debonded 5Y-TZP zirconium crowns should not be reused due to a reduction in mechanical strength. This conclusion, however, does not align with the results of our study. In our research, a lower-power laser was utilized, and a different type of ceramic was evaluated. Furthermore, the test method used to evaluate the mechanical properties in our study differed from those in the previous study.

Kurtulmuş Yılmaz et al. (7) roughened the intaglio surfaces of lithium disilicate ceramics using an Er,Cr:YSGG laser and found that low-energy laser application (2W) reduced the FS of lithium disilicate ceramics less than other roughening methods. Contrary to these findings, the results of our study indicate that lithium disilicate ceramics were not affected by laser application, even at high energy levels(3.5W) . This discrepancy may be attributed to the shorter duration time of laser application to the sample surfaces in this study.

The fundamental mechanical characteristic of dental ceramics is hardness, which indicates resistance to indentation (24). According to Hallmann et al. (25), laser processing of hot-pressed lithium silicate ceramics will affect the hardness of ceramic samples. In our investigation, we found that the hardness of the dental ceramic material decreased only in the aged and laser-applicated samples following Er,Cr:YSGG laser treatment. There have been only a limited number of investigations (15,25) into the mechanical properties of dental ceramic materials following laser treatment, and this study contributes to the body of knowledge in this area.

When the FESEM results of this study were examined, no microcracks or fractures were found on the ceramic surface, and similar laser ablation craters were observed in the laser-applied samples. Salem et al. (20) found that IPS e.max CAD exhibited significant changes in surface roughness after thermocycling. These results are consistent with the findings of this study, where higher roughness was observed in aged samples.

Additionally, the Ra values of aged samples, both with and without laser application, are quite similar. These findings need to be corroborated by further studies.

This laboratory study establishes an experimental basis for the reuse of Er,Cr:YSGG laser-debonded lithium disilicate ceramics, whether they are removed immediately after cementation or after intraoral use. It should be noted that this study was conducted in vitro and may not accurately represent in vivo conditions. The scope of the study was limited to evaluating a single type and thickness of dental ceramic. Furthermore, the study did not examine various laser parameters. Further clinical research is necessary to corroborate the findings of this investigation.

CONCLUSION

Within the limitations of this study, artificial aging significantly reduces the FS of lithium disilicate ceramics. Er,Cr:YSGG laser debonding does not affect the FS or FM of lithium disilicate ceramics. Restorations that need to be removed immediately after cementation may be reused following Er,Cr:YSGG laser debonding, as their mechanical properties remain unaffected. Aged restorations may be reused after Er,Cr:YSGG laser debonding; however, it should be noted that aging reduces the FS of the restoration.

Acknowledgments

None

Authorship contributions

Concept: DGÜ, PY, NNÇK; Design: DGÜ, PY, NNÇK; Data Collection or Processing: PY, NNÇK; Analysis or Interpretation: DGÜ, PY; Literature Search: DGÜ; Writing: DGÜ, PY.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declaration of competing interest

The authors declared no conflict of interest.

Ethics

This article does not contain any studies with human participants or animals performed by any of the authors.

Funding

This work has not received any funding support.

REFERENCES

1. Kassardjian V, Varma S, Andiappan M, Creugers NHJ, Bartlett D. A systematic review and meta-analysis of the longevity of anterior and posterior all-ceramic crowns. J Dent 2016; 55: 1–6.
2. Deeb JG, Grzech-Leśniak K, Brody ER, Matys J, Bencharit S. Erbium laser-assisted ceramic debonding: a scoping review. J Prosthodont 2022; 31: 100-24.
3. Morford CK, Buu NC, Rechmann BM, Finzen FC, Sharma AB, Rechmann P. Er:YAG laser de-bonding of porcelain veneers. Laser Surg Med 2011; 43: 965–74.
4. Rechmann P, Buu NCH, Rechmann BMT, Le CQ, Finzen FC, Featherstone JDB. Laser all-ceramic crown removal-a laboratory proof of principle study-phase 1 material characteristics. Lasers Surg Med 2014; 46: 628–35.
5. Rechmann P, Buu NCH, Rechmann BMT, Finzen FC. Laser all ceramic crown removal-a laboratory proof-of-principle study-phase 2 crown debonding time. Lasers Surg Med 2014; 46: 636–43.
6. Demetoğlu GA, Zortuk M. Effect of Surface Treatments on Leakage of Zirconium Oxide Ceramics. Meandros Med Dent J 2016; 17: 64–9.
7. Kurtulmus-Yilmaz S, Cengiz E, Ongun S, Karakaya I. The effect of surface treatments on the mechanical and optical behaviors of CAD/CAM restorative materials. J Prosthodont 2019; 28: 496-503.
8. Ozdogan A, Yesil Duymus Z. Investigating the effect of different surface treatments on Vickers hardness and FS of zirconium and lithium disilicate ceramics. J Prosthodont 2020; 29: 129–35.
9. Zanini NA, Rabelo TF, Zamataro CB, Caramel-Juvino A, Ana P A, Zezell DM. Morphological, optical, and elemental analysis of dental enamel after debonding laminate veneer with Er, Cr: YSGG laser: A pilot study. Microsc Res Tech 2021; 84: 489-98.
10. Al-Karadaghi SS, Jawad HA. Debonding of LDSVs utilising Er, Cr: YSGG laser irradiation with fractional technique: An in vitro study. Aust Dent J 2023; 68: 125-34.
11. Cifuentes HG, Gómez JC, Guerrero ANL, Muñoz J. Effect of an Er, Cr: YSGG laser on the debonding of lithium disilicate veneers with four different thicknesses. J Lasers Med Sci 2020; 11: 464.
12. Amin BK. Effects of Er, Cr: YSGG Laser Application in De-Bonding of Different Ceramic Veneer Materials (In Vitro Study). Coatings 2023; 13: 1352.
13. Yıldız P, Güneş Ünlü D, Talay Çevlik E, Üşümez A. Removal of lithium disilicate veneers with Er, Cr: YSGGL laser: now? Or after ageing? Lasers Med Sci 2022; 38: 12.
14. Oztoprak MO, Tozlu M, Iseri U, Ulkur F, Arun T. Effects of different application durations of scanning laser method on debonding strength of laminate veneers. Lasers Med Sci 2012; 27: 713–6.

15. Zhang X, Dong H, Guo C, Zhang X, Zhang D, Wu X, Zhao J. Effects of laser debonding treatment on the optical and mechanical properties of all-ceramic restorations. Lasers Med Sci 2021; 36: 1497-504.
16. Wendler M, Belli R, Petschelt A, Mevec D, Harrer W, Lube T, et al. Chairside CAD/CAM materials. Part 2: FS testing. Dent. Mater 2017; 33: 99–109.
17. Tavares LDN, Zancopé K, Silva ACA, Raposo LHA Soares CJ, Neves FDD. Microstructural and mechanical analysis of two CAD-CAM lithium disilicate glass-reinforced ceramics. Braz Oral Res 2020; 34; 1–10.
18. Munoz A, Zhao Z, Paolone G, Louca C, Vichi A. FS of CAD/CAM Lithium-Based Silicate Glass–Ceramics: A Narrative Review. Materials 2023; 16: 4398.
19. Vasiliu RD, Porojan SD, Bîrdeanu MI, Porojan L. The effect of thermocycling and surface treatments on the surface roughness and microhardness of three heat-pressed ceramics systems. Crystals (Basel) 2020; 10: 160.
20. Salem BO, Elshehawi DM, Elnaggar GA. Fracture resistance of pressed ZLS crowns versus pressed LD crowns under thermomechanical cycling. Braz Dent J 2022; 33: 103–9.
21. Juntavee N, Juntavee A, Chansathien O, Prasertcharoensuk N, Leesuraplanon B. FS of Different Monolithic Computer-Assisted Design and Computer-Assisted Manufacturing Ceramic Materials Upon Accelerated Aging. Eur J Dent 2024; 14.
22. Kim SH, Choi YS, Kang KH, Att W. Effects of thermal and mechanical cycling on the mechanical strength and surface properties of dental CAD-CAM restorative materials. J Prosthet Dent 2022; 128: 79-88.
23. Birand C, Kurtulmus-Yilmaz S. Evaluation of Er, Cr: YSGG laser irradiation for debonding of zirconia hybrid abutment crowns from titanium bases. Lasers Med Sci 2022; 37: 2675-85.
24. Colombo M, Poggio C, Lasagna A, Chiesa M, Scribante A. Vickers micro-hardness of new restorative CAD/CAM dental materials: evaluation and comparison after exposure to acidic drink. Materials (Basel) 2019; 16: 12.
25. Hallmann L, Ulmer P, Gerngross MD, Jetter J, Mintrone M, Lehmann F, et al. Properties of hot-pressed lithium silicate glass-ceramics. Dent Mater 2019; 35: 713–29.