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REVIEW ARTICLE

Impact of Surface Treatment and Ultrasonic Cleaning on Bond Strength of Lithium Disilicate Restorations: A Systematic Review Comparing Various Bonding Protocols

S. Subash Sharma[1], Monisha Bhate[2], Aravind Kumar Subramanian[3]

[1]Department of Aesthetics, Saveetha Dental College and Hospital, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India, [2]Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospital, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India, [3]Department of Orthodontics, Saveetha Dental College and Hospital, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India

Abstract

Lithium disilicate restorations are widely used in restorative dentistry because of their excellent esthetics and mechanical properties. However, achieving optimal bond strength between the restoration and the resin cement is essential for their long-term clinical success. This systematic review aimed to evaluate the effects of different surface treatments on the bond strength of lithium disilicate restorations. A comprehensive literature search was conducted using Medical Subject Headings (MeSH) terms and relevant keywords in PubMed Advanced, Cochrane Library, Web of Science, and Google Scholar for studies published up to October 2024. Twelve articles were identified through the electronic search, of which six met the predefined inclusion criteria and were included in the review. The findings highlighted the importance of appropriate surface treatment and ultrasonic cleaning in improving the bond strength of lithium disilicate restorations. The combination of phosphoric acid re-etching and ultrasonic cleaning appeared to be particularly effective in enhancing adhesion. Hydrofluoric acid etching may leave surface residues that adversely affect bonding, while ultrasonic cleaning can help remove these residues and improve the surface condition. Within the limitations of the included studies, the findings suggest that phosphoric acid re-etching followed by ultrasonic cleaning may improve the bond strength of lithium disilicate restorations. However, further standardized studies are needed to validate these findings and establish reliable clinical protocols.

Key words: Lithium disilicate; Surface treatment; Bond strength; Hydrofluoric acid etching; Phosphoric acid; Ultrasonic cleaning; Resin cement; Dental ceramics

INTRODUCTION

Due to their aesthetic and mechanical properties, one of the reasons that lithium disilicate ceramics have become popular in restorative dentistry is that they can be used to make single crowns and multiple-unit bridges.[1] They can also be used to make fixed restoration of several kinds. They can be used to fabricate full coverage crowns, veneers, inlays, onlays, etc.[2] The success of lithium disilicate restorations largely depends on the bond strength achieved between the ceramic and the tooth. Many factors affect bonding and include treatment of the restoration surface, cleaning, and type of adhesive used.[3]

In a conventional approach, treatments used to achieve bonding of the restoration to the tooth include application of acid, silane, and adhesive. While these methods, when

Address for correspondence:
Dr. S. Subash Sharma, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospital, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India.
E-mail: subash@saveetha.com

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combined, achieve bond strengths satisfactorily, there is variability due to differences in techniques and materials.[4] With the rapid growth of dental materials and technology, new strategies aimed at improving the adhesion of lithium disilicate restorations are becoming increasingly popular.[5]

Ultrasonic cleaning has benefits in surface preparation by removing materials and improving bond strength,[6] but has not been well studied with various surface treatments like sandblasting, hydrofluoric acid (HF) etching, and silanization. Not much literature has examined these surface treatments and other cleaning methods in relation to the traditional bonding methods; therefore, a lack of guidelines that would improve bond strength exists.[7]

There are already established studies on lithium disilicate restorations and bonding techniques, but a need still exists for a thorough systematic review to summarize what is currently published to include the effect of surface treatments and ultrasonic cleaning on bond strength.[8] This will address the gaps that currently exist by systematically reviewing the available literature on various surface treatments before a bonding protocol. This will enable clinicians to make more informed decisions on how to maximize the longevity and performance of lithium disilicate restorations.

Aim

This study will determine the impact of various surface treatments on the bond strength of lithium disilicate restorations.

RESEARCH QUESTION

What is the effect of diverse surface treatments and ultrasonic cleanings on the bond strength of lithium disilicate restorations, and how do various bonding protocols affect the best adhesion potential to dental substrates?

NULL HYPOTHESIS

The null hypothesis is bond strength of lithium disilicate restorations to dental substrates is unaffected by the combination of surface treatment, ultrasonic cleaning and bonding protocol.

ALTERNATE HYPOTHESIS

The alternative hypothesis is bond strength of lithium disilicate restorations to dental substrates is impacted by the combination of surface treatment, ultrasonic cleaning and bonding protocol used.

The criteria for the studies to be included in this research are *in vitro* studies that use lithium disilicate restorations, include ultrasonic cleaning in their surface cleaning method(s), and measure bond strength of glass-ceramic materials.

The studies that will be excluded are the following: Unpublished studies, those done in languages other than English, those that do not include ultrasonic cleaning as a surface cleaning method, or those that focus on materials other than glass ceramics.

MATERIALS AND METHODS

For the purpose of this systematic review, the published relevant literature was gathered by a comprehensive electronic search performed on PubMed Advanced Search, Google Scholar, Cochrane Library, and Web of Science. A PubMed search was conducted using relevant Medical Subject Headings terms and keywords, with a cut-off date of October 2024. The aim of the search strategy was to locate *in vitro* studies that examined the effect of different surface treatments, ultrasonic cleaning and/or bonding protocols on the bond strength of lithium disilicate restorations to the dental substrates.

The framework of population, intervention, comparison, outcomes, and study was used to evaluate the studies. The Population (P), in this case, consisted of studies that focused on lithium disilicate restorations bonded to dental substrates of either enamel or dentin via extracted or/and prepared tooth samples. The Intervention (I), in this case, consisted of ultrasonic cleaning of lithium disilicate restorations before the bonding procedure. For the Comparison (C), studies were considered in which different surface treatments and/or bonding protocols to lithium disilicate restorations were analyzed. The Outcome (O) of this research was the evaluation of the bond strength of lithium disilicate restorations to dental substrates using different types of mechanical tests (e.g. shear bond strength [SBS] and tensile bond strength). The Select Studies (S) consisted of studies that focused on *in vitro* investigations of the different surface treatments, ultrasonic cleaning methods, and bonding protocols for lithium disilicate restorations, and were included in this systematic review. The study selection process is presented in Figure 1.

The studies excluded during the screening process, together with the reasons for exclusion, are summarized in Table 1.

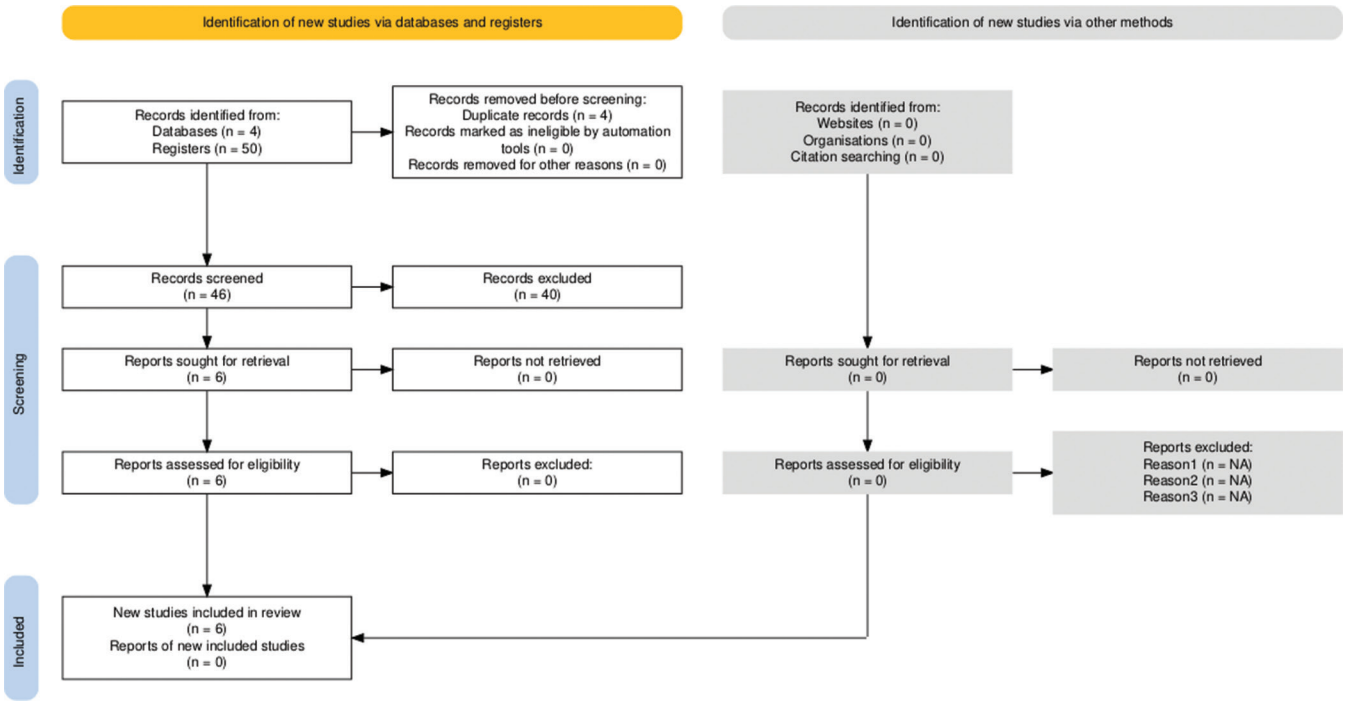


Figure 1: Preferred reporting items for systematic reviews and meta-analyses flow diagram

The characteristics, study groups, sample sizes, outcome measures, and key findings of the six included studies are summarized in Table 2.

Risk of bias assessment was done using the Quin Tool. The risk of bias assessment for the six included studies is presented in Table 3.

The included studies were assessed using the Quin tool for assessment. Of the 6 included studies, 5 demonstrated low risk of bias while 1 demonstrated medium risk of bias. Studies with low risk of bias effectively explained their aim and objectives, stated how sampling was carried out, described the test and comparison group, and the type of statistical analysis. One study designated to medium risk of bias did not describe the sampling frame and the sampling method employed.

RESULTS

A total of 50 studies were generated from the primary search. Following the removal of duplicates and studies that were not in the English language, a total of 46 studies were analyzed. After the relevance of the titles to the objective was assessed, a total of 37 studies were excluded, leaving a total of 9 studies for review of the abstracts. After review of the full text, a total of 3 studies were excluded, leaving a total of 6 studies for review. After the studies were assessed based on the inclusion criteria, a total of 6 studies were determined to be appropriate for the review. This systematic review therefore included a total of 6 studies that satisfied the minimum requirements.

DISCUSSION

In the study by Lapinska *et al*., secondary ion mass spectroscopy (SIMS) examined the changes observed in the pre-etched ceramic surfaces after exposure to different cleaning techniques. The SBS, basically the peeling force, of both glass ceramic (lithium disilicate and leucite) specimens was dependent on the cleaning methodology used. The combination of re-etching with phosphoric acid (H_3PO_4) followed by an ultrasonic bath was the best cleaning technique employed in this study.[9]

Likewise, Pilecco *et al*. showed that cleaning with evaluation pastes affected the bond strength of resin cement to lithium disilicate ceramics. Ultrasonic cleaning with distilled water, removal of ceramics with 37% phosphoric acid, and application of 5% HF to the lithium disilicate surface were reported to achieve optimal cleaning and adhesion. It was observed that bond strength was negatively affected by bonding interfaces with contaminated materials in various restorative procedures.[10]

Belli *et al*. reported that the etching of ceramic with HF lead to the formation of a white opaque ceramic, which ruptured the continuity of the ceramic. Depending on the silica content and crystalline structure of the ceramic, different ceramic phases began to dissolve due to the interaction of the ceramic with the different types of acids and time. These precipitates obstruct the proper wetting and infiltration of the resin, reducing bond strength between ceramic and composite. It was reported that in their microtensile bond strength test, leaving etching residues on ceramics negatively affected bond strength, reinforcing the need

Table 1: Excluded studies

PMID	Title	Authors	Citation	First author	Journal	Publication year	DOI	Reason for exclusion
34219445	Effects of surface treatment procedures on bond strength of lithium disilicate glass ceramic	Peng Yu, Xiao Yan Wang	Chin J Dent Res. 2021 Jun 23;24 (2):119-124. doi: 10.3290/ j.cjdr. b1530491.	Peng Yu	Chinese Journal of Dental Research	2021	10.3290/j.cjdr. b1530491	Outcome parameter not similar
34422055	The influence of different surface cleansing agents on shear bond strength of contaminated lithium disilicate Ceramic: An *in vitro* study	Taksid CharasseangpaisarnPattarawadee KrassanairawiwongChanidapa SangkanchanavanichAtima KurjirattikanKanyarak KunyawatyuwapongNatlada Tantivasin	Int J Dent 2021 Aug 10:2021: 7112400. doi: 10.1155/2021/ 7112400. eCollection 2021	Taksid Charasseangpaisarn	International Journal of Dentistry	2021	10.1155/2021/ 7112400	Study groups do not include the group of interest
24919532	Effect of different cleaning regimens on the adhesion of resin to saliva-contaminated ceramics	Akın Aladağ1, Bahar Elter, Erhan Çömlekoğlu, Burcu Kanat, Mehmet Sonugelen, Atilla Kesercioğlu, Mutlu Özcan	J Prosthodont. 2015 Feb; 24 (2):136-45. doi: 10.1111/ jopr. 12170. Epub 2014 Jun 11.	Akın Aladağ	Journal of Prosthodontics	2015	10.1111/jopr. 12170	Outcome parameter not similar

Table 2: Included studies

Title	Author	Journal	Year	Study design	Groups	Sample size	Outcome measures	Key findings
Effect of Surface cleaning regimen on glass-ceramic bond strength	Lapinska *et al.*	MDPI molecules	2019	*In vitro*	Group 1- No additional cleaning Group 2- Ultrasonic bath (distilled water 5 min) Group 3- Cleaning with H_3PO_4 (1 min) Group 4- Cleaning Paste (Ivoclean, 1 min) Group 5- Re- etching (9% HF, 20s)	*n*=23 in each group	Surface Elemental Analysis Bond Strength (Shear Bond Strength testing using Universal testing machine)	The most effective cleaning method for the saliva-contaminated leucite glass ceramic was cleaning with H3PO4, and for lithium disilicate glass it was re-etching with HF
Bond strength of lithium disilicate after cleaning methods of remaining hydrofluoric acid	Santos *et al.*	Journal of Clinical and Experimental Dentistry	2020	*In vitro*	Group C (Control, no treatment) Group HF+S (5% Hydrofluoric acid+silane) Group HF+US+S (5% hydrofluoric acid+ultrasound cleaning+silane) Group HF+PH+S (5% hydrofluoric acid+37% phosphoric acid+Silane	*n*=11 in each group	Shear bond strength testing	Based on the results encountered, the utilization of cleaning procedure after the conditioning with hydrofluoric acid is extremely important. These procedures increased the bond strength between lithium disilicate and resin cement, especially after ultrasonic cleaning
Post-etching cleaning influences the resin shear bond strength to CAD/CAM lithium disilicate ceramics	Bruzi *et al.*	Applied Adhesion Science	2017	*In vitro*	AW- Air/Water spray UB- Ultrasonic Bath PA- 37% Phosphoric acid ST- Steam Cleaning E- No Silane Treatment	*n*=24	Shear bond strength testing	Etching lithium disilicate ceramics following by ultrasonic bath cleaning and regular application of a silane is recommended
Post-etching cleaning and resin/ceramic bonding: Microtensile bond strength and EDX analysis	Belli *et al.*	Journal of Adhesive Dentistry	2009	*In vitro*	Group 1- No cleaning Group 2- Air water spray Group 3- Phosphoric acid Group 4- Ultrasonic bath Group 5- Phosphoric acid+ultrasonic bath Group 6- Clearfil Silane kit	*n*=12	Microtensile bond strength testing (Instron 4444)	Post-etching cleaning methods had statistically different influences on the bond strength for the IPS Empress Esthetic ceramic system.
Evaluation paste removal method and bond strength between resin cement and lithium disilicate ceramic: An *in vitro* study	Pilecco *et al.*	The Journal of Prosthetic Dentistry	2023	*In vitro*	Group 1- Air-water spray Group 2-37% Phosphoric acid Group 3- Ultrasonic bath Group 4- Cleaning paste Group 5- Conventional surface treatment	*n*=56	Micro-shear bond strength	For optimal bond strength between lithium disilicate and resin cement after evaluation paste use, cleaning the ceramic surface with 37% phosphoric acid, ultrasonic bath or hydrofluoric acid worked best

(Contd...)

Table 2: *(Continued)*

Title	Author	Journal	Year	Study design	Groups	Sample size	Outcome measures	Key findings
Effects of two different acid etching and surface washing methods on bond strength on different CAD-CAM Blocks under aging protocols	Çınar *et al.*	Biomed Research Journal	2023	*In vitro*	Group 1- Hydrofluoric acid and washing Group 2- Hydrofluoric acid and ultrasonic washing Group 3- Hydrofluoric acid and phosphoric acid Group 4- Monobond etch and prime and washing Group 5- Monobond etch and prime and ultrasonic washing Group 6- Monobond etch and prime and phosphoric acid	*n*=9 for each group	Shear bond strength testing (Shimadzu universal machine)	In cases where high bond strength is the first priority, zirconia reinforced glass ceramics should be preferred over lithium disilicate glass ceramics. In addition, ultrasonic washing gives better results than washing with phosphoric acid in clinical routine.

CAD: Computer-aided design, CAM: Computer-aided manufacturing, HF: Hydrofluoric acid

for cleaning after etching and depending on the ceramic system.[11]

Çınar *et al*. noted that after the removal of lithium disilicate ceramics with phosphoric acid cleaners, the highest bond strength values were obtained by ultrasonic cleaning.[12]

Dos Santos *et al*. remarked that groups that went through cleaning procedures had higher SBS values than the control groups and conventional protocols. After using ultrasonic cleaning with HF, the glass-ceramic surface was free of fluorosilicate precipitates and showed an improvement in SBS values. HF selectively etches glass-ceramics and creates surface modifications that enhance micromechanical retention. However, if HF acid residues are not completely removed from the ceramic surface, they can negatively affect adhesion, flexural strength and can create an additional risk for the patient due to toxicity. Thus, it is vitally important to completely remove these residues. In addition, the HF etching process forms an open structure which, after being in contact with water, can disrupt the siloxane network. Phosphoric acid, on its own, could not completely eliminate fluoride precipitates, which was confirmed by scanning electron microscopy (SEM) images and energy-dispersive spectroscopy analysis, which also mapped surface fluorine.[13]

In the study of Bruzi *et al*. post-etching ultrasonic bath cleaning reached the best SBS values (21 MPa). Of all the cleaning protocols evaluated by SEM, the ultrasonic bath resulted in the cleanest ceramic surface.[14]

The use of lithium disilicate ceramics in restorative dentistry has been widely adopted because of their excellent mechanical properties, aesthetic appeal, and excellence in transformability. However, the success of these restorations is highly dependent on the surface treatment that is performed before bonding.[15] This review evaluates ultrasonic cleaning and compares it to other surface treatments: phosphoric acid etching, air abrasion, air-water spray, laser irradiation, micro silica particles, and silicatization, to determine their effect on bonding strength and surface integrity.

Ultrasonic cleaning

Ultrasonic cleaning is used to decontaminate the surface of lithium disilicate restorations after the try-in, removing saliva, blood, and temporary cements. It utilizes a cleaning solution along with a high-frequency sound wave to agitate a cleaning solution, which dislodges the contaminant without affecting the microstructure of the surface.[16] This preserves the integrity of the material and reduces the risk of developing microcracks or surface damage. As compared to other models of mechanical treatment, ultrasonic cleaning is less aggressive. It does, however, lack the ability to produce the micromechanical roughness required for improved adhesion,

Table 3: Risk of bias assessment

Criteria	Lapinska *et al.*	Santos *et al.*	Bruzi *et al.*	Belli *et al.*	Pilecco *et al.*	Çınar *et al.*
Clearly stated aims/objectives	2	2	2	2	2	2
Detailed explanation of sample size calculation	2	2	1	2	2	2
Detailed explanation of sampling technique	2	2	1	2	2	2
Details of comparison group	2	2	2	2	2	2
Detailed explanation of methodology	2	2	2	2	2	2
Operator details	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Randomization	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Method of measurement of outcome	2	2	2	2	2	2
Outcome assessor details	1	1	1	1	1	1
Blinding	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Statistical analysis	2	2	2	2	2	2
Presentation of results	2	2	2	2	2	2

and therefore it is usually only the initial step in the sequence of treatments that precede etching or silane application.[17]

The main advantage of ultrasonic cleaning is the fact that it is the least mechanical of all the cleaning models, and therefore is capable of removing contamination while leaving the material's surface texture and structure intact.[18] This is unlike air abrasion and laser treatments that actually remove surface material. Since ultrasonic cleaning does not damage the restoration, it can be used to prepare the surface for subsequent treatments to afford micromechanical retention and chemical bonding.[19] Thus, it is an excellent, non-damaging accompaniment to other surface treatments for lithium disilicate.

Phosphoric acid etching

Phosphoric acid etching is the most common method for both cleaning and decontaminating the surface of ceramics and removing organic and inorganic materials. Although efficient for cleaning, the limited roughening of the lithium disilicate surface by phosphoric acid limits its contribution to strengthening the bond. Phosphoric acid etching is utilized along with other procedures, most notably the application of silane, to improve chemical bonding of ceramics and resin cement.[20]

Air abrasion

Air abrasion uses aluminum oxide particles and is a more aggressive technique for surface roughening, and consequently an improvement in bond strength, through an increase in micromechanical interlocking. Unfortunately, the abrasive nature of the process can lead to damage of the surface microstructures and the formation of microcracks that can ultimately affect the longevity of restorations. Although air abrasion improves bond strength, it may decrease material's fracture resistance.[21]

Air-water spray

The air-water spray method is similar to ultrasonic cleaning for restorations. Post-contamination, it is used for cleaning restoration. Air-Water spray has no significant effect on the bond strength and is similar to other methods in the decontamination of restoration, lacking the mechanical effects of other methods such as air abrasion and laser irradiation.[22]

Laser irradiation

Laser irradiation is a newer method for laser surface treatment of lithium disilicate restorations. This method removes a small amount of surface material through ablation, resulting in an increased surface area suitable for bonding. Compared to air abrasion or HF etching, laser-treated surfaces have been shown to achieve similar levels of surface roughness.[23] Variability in the results is typically greatest for different laser types and different settings, making it more challenging to control the results of laser surface treatments when compared to other standard methods.

Micro-silica particles

The application of micro-silica particles through a process called tribochemical silica coating provides both mechanical and chemical bonding. This process increases the surface

area of ceramic and modifies the surface with silica particles to enhance the bond of resin-based materials.[24] The combination of micromechanical retention and chemical interaction makes micro-silica particles a highly effective surface treatment for lithium disilicate.

Silicatization

Silicatization refers to the application of a silica layer to the surface of the ceramic that enhances both mechanical and chemical bonding. Along with the application of silane coupling agents, silicatization improves bond strength.[25] Like micro-silica particles, silicatization improves the durability of bonding lithium disilicate restorations to resin cements.

Comparative analysis

While ultrasonic cleaning is not a surface treatment for improving adhesion by itself, it is useful for removing contaminants before a treatment. Unlike other methods that modify the surface, ultrasonic cleaning preserves the structure of the restoration.[26] Air abrasion and silicatization improve the bond strength of materials by retaining micromechanical interactions and forming chemical bonds.

Air abrasion presents a danger of damaging the ceramic surface, whereas ultrasonic cleaning does not pose this risk.[27] As for phosphoric acid etching, while a surface cleaner, it is largely insufficient as a roughening agent. More successful, at least for the time being, are treatments that incorporate mechanical and chemical adhesion such as micro-silica. Although best reserved for after ultrasonic cleaning, micro-silica applications are more successful than other treatments.

Ultrasonic cleaning, by itself, is not sufficient to dramatically improve the bond strength of lithium disilicate, but as a decontamination before surface modifications, ultrasonic cleaning is quite useful.[9] Beyond ultrasonic cleaning, surface modifications such as silicatization, air abrasion, etc. may be implemented. The application of other surface treatments coupled with ultrasonic cleaning will greatly improve the strength of lithium disilicate restorations.

CONCLUSION

The importance of surface treatment and ultrasonic cleaning in improving the bond strength of lithium disilicate restorations is now evident. It is generally agreed that phosphoric acid re-etch, followed by ultrasonic cleaning, is the most effective. It was shown that other methods that do not fully remove contaminants, especially after HF etching, are often insufficient. Ultrasonic cleaning was shown to considerably enhance bond strength by removing residual contaminants. When designing a treatment, surface modifications and post-etch cleaning protocols have to be addressed. A great deal more research has to be conducted, especially in the long-term durability of bonding techniques. Standardization of surface cleaning for different ceramics has to be implemented.

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