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Is the adhesive or mechanical behavior of glass ceramics influenced by the adhesive layer application after etching and silanization? A literature review

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Aim: This review investigated the effect of applying an adhesive after surface treatment of glass-ceramics on the bonding, mechanical or clinical behavior. **Methods:** Studies comparing the adhesive, mechanical or clinical behavior of glass-ceramics, with or without adhesive application after surface treatment, were included. Searches were performed in PubMed, Scopus, and Web of Sciences databases (January 2022), resulting in 15 included studies. **Results:** Regarding the evaluated outcomes, 13 studies assessed bond strength, 2 studies assessed biaxial flexural strength and 1 study assessed fatigue failure load, while no study evaluating clinical outcomes was included. It was possible to observe that the adhesive application after ceramic surface treatment was unfavorable or did not influence the evaluated outcomes. **Conclusion:** Most of the evidence available in the literature shows that the adhesive application after surface treatment does not improve the adhesive and mechanical behavior of glass-ceramics.

Keywords: Dental adhesives. Ceramics.

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Introduction

Dental ceramics can currently be classified into three categories according to their composition: glass-matrix ceramics (glass-ceramics): non-metallic inorganic ceramic materials containing glass phase; polycrystalline ceramics: non-metallic inorganic ceramic materials without glass phase; and resin-matrix ceramics: polymeric matrix containing inorganic compounds, which may include glass-ceramics[1].

Glass-ceramics have been widely used for indirect restorations since they combine excellent physical and chemical properties and present excellent esthetics[2,3]. In addition to choosing the glass-ceramic according to the clinical indication, another fundamental factor for the longevity of ceramic restorations is the use of an adequate protocol of adhesive luting[4]. The conventional protocol for glass-ceramics includes etching the ceramic surface with hydrofluoric acid (HF), which selectively attacks the glassy phase and exposes the silicon dioxide (SiO_2), causing morphological changes that contribute to micromechanical retention of the resin cement to the material[5-7]; and the application of the silane coupling agent, which chemically reacts with the exposed silicon dioxide and promotes a chemical bond between the ceramic and the resin cement[8,9].

For adequate restoration behavior, it is essential that the surface irregularities resulting from the etching of HF are completely filled in by the resin cement, since unfilled spaces at the adhesive interface can negatively influence the performance of ceramic restorations[10]. In this sense, studies have suggested applying an adhesive layer on the ceramic surface before applying resin cement[11-14]. This adhesive layer could improve the wettability of the ceramic surface, as its viscosity is lower than that of the resin cement, which would facilitate the filling of irregularities.

However, there are still conflicting statements in the literature about the use of an adhesive after ceramic surface treatment, which makes it difficult to define an ideal technique. Although Nogueira et al[15] (2021) showed that the application of an adhesive layer on glass-ceramics after surface treatment does not improve the bond strength values, an updated synthesis of the literature addressing other outcomes becomes relevant. Thus, the aim of the present review was to investigate the effect of applying an adhesive after surface treatment of glass-ceramics on the adhesive, mechanical or clinical behavior.

Materials and methods

Focused question

Does the application of an adhesive after surface treatment improve the adhesive, mechanical or clinical behavior of glass-ceramics?

PICOs

This literature review adopted the population, intervention, comparison, and outcomes process (i.e. the "PICOs" process), as follows:

Population: Glass-ceramics.

Intervention: Adhesive layer application.

Comparison: Non-adhesive layer application.

Outcomes: Adhesive, mechanical and clinical behavior.

Study design: *In vitro* and clinical studies.

Eligibility criteria

Inclusion criteria

Studies in dentistry which considered the adhesive, mechanical or clinical behavior of all glass-ceramics cemented using adhesive strategies were selected (i.e. ceramics used as intra radicular posts, or at implant abutment or pillar contexts were not considered). Studies comparing the adhesive, mechanical or clinical behavior of glass-ceramics, with or without adhesive application after surface treatment, regardless of the glass-ceramic used (e.g., feldspathic, leucite, lithium disilicate, lithium silicate, among others), the processing method for ceramic manufacturing (layering, pressing, or CAD/CAM techniques, among others), bond strength methodology (shear, micro-shear, tensile, micro-tensile, among others), mechanical property measured (strength, hardness, toughness, among others), regardless of the testing method (monotonic, fatigue, among others) and clinical outcome were included. All existing *in vitro* or clinical studies on such themes were included regarding the adopted study design.

Exclusion criteria

Studies which did not adopt ceramic surface pretreatment including HF etching and application of silane coupling agent were excluded.

Search

The PubMed, Web of Science and Scopus databases were consulted, without date restriction (last executed on January 10, 2022). The search strategy (Table 1) was based on the Mesh terms and the specific free-text terms of PubMed, which were then adapted, if necessary, for the other databases.

Table 1. Search strategy.

PubMed
(“ceramics” [Mesh] OR ceramic [tiab] OR “dental porcelain” [Mesh] OR porcelain [tiab] OR Glass ceramic [tiab] OR Feldspathic [tiab] OR Lithium disilicate [tiab] OR lithium silicate [tiab] OR Leucite [tiab]) AND (adhesives [MeSH] OR “tissue adhesives” [MeSH] OR “dentin-bonding agents” [MeSH] OR dentin bonding [tiab] OR bonding agent [tiab] OR dental adhesive system [tiab] OR luting strategies [tiab]) AND (Adhesion [tiab] OR Bond strength [tiab] OR “Survival Rate”[Mesh] OR Clinical survival [tiab] OR clinical performance [tiab] OR mechanical behavior [tiab] OR mechanical properties [tiab] OR “Fatigue” [Mesh] OR Fatigue [tiab] OR load bearing OR Fracture strength [tiab] OR failure load [tiab] OR Resistance [tiab] OR compression [tiab] OR retention [tiab] OR tensile [tiab])

Continue

Continuation

Web of Science
TS=(ceramic OR porcelain OR Glass ceramic OR Feldspathic OR Lithium disilicate OR lithium silicate OR Leucite) AND TS=(adhesives OR dentin bonding OR bonding agent OR dental adhesive system OR luting strategies) AND TS=(Adhesion OR Bond strength OR Survival Rate OR Clinical survival OR clinical performance OR mechanical behavior OR mechanical properties OR Fatigue OR load bearing OR Fracture strength OR failure load OR Resistance OR compression OR retention OR tensile) AND SU= (Dentistry) NOT TS=(review)
Scopus
TITLE-ABS-KEY (“ceramic” OR “porcelain” OR “Glass ceramic” OR “Feldspathic” OR “Lithium disilicate” OR “lithium silicate” OR “Leucite”) AND TITLE-ABS-KEY (“adhesives” OR “dentin bonding” OR “bonding agent” OR “dental adhesive system” OR “luting strategies”) AND TITLE-ABS-KEY (“Adhesion” OR “Bond strength” OR “Survival Rate” OR “Clinical survival” OR “clinical performance” OR “mechanical behavior” OR “mechanical properties” OR “Fatigue” OR “load bearing” OR “Fracture strength” OR “failure load” OR “Resistance” OR “compression” OR “retention” OR “tensile”) AND NOT (“review”) AND (LIMIT-TO (SUBJAREA,”DENT”))

Screening

Screening was performed using a reference manager (EndNote X9, Thomson Reuters, New York, NY) by two independent researchers (H.C.V. and P.S.M.). First, titles and abstracts were analyzed for relevance and the presence of the eligibility criteria and then classified as included, excluded or uncertain. The full text of the studies included in the first phase was analyzed again in a second moment regarding the eligibility criteria by the same two reviewers mentioned above (acting independently). Discrepancies in the review of titles/abstracts and full text were resolved by discussion.

Data collection

The following data were collected in a spreadsheet (Microsoft Excel, Redmond, WA): year of publication, country of origin, type of vitreous ceramic, adhesive system, cementing agent, aging protocol, evaluated outcome / type of test, predominant failure type and main result in relation to the use of adhesive (favorable to the outcome, no difference or unfavorable).

Data analysis

Data were summarized in tables and figures in order to describe the main characteristics of the included studies.

Results

A total of 3,133 studies were initially identified. Then, a total of 40 studies were considered eligible for full-text evaluation after removing duplicates and evaluating titles and abstracts, of which 15 were included for qualitative analysis (Figure 1).

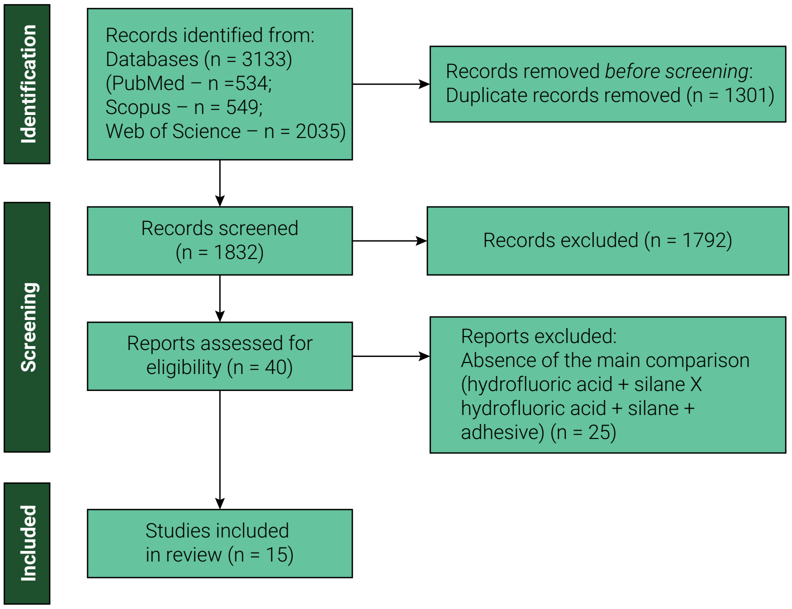

Figure 1. Study selection diagram.

Table 2 presents a qualitative synthesis of the articles included in the review. The articles included were published between 2003 and 2021, with most of them published from 2015 onwards and by Brazilian authors. A total of 13 commercial adhesive brands were evaluated. All studies that met the criteria were in vitro studies, without clinical studies entering the final review. It was possible to observe that the adhesive application after ceramic surface treatment was unfavorable or at least did not influence the evaluated outcomes regarding the adhesive and mechanical behavior of glass-ceramics, except for particular groups in non-aged regimes[12,16,17].

Table 2. Descriptive synthesis of the included studies.

Author (year)	Country	Type of glass-ceramic	Adhesive system	Resin Cement	Aging	Outcome evaluated/ type of test	Predominant failure type	Results*
El Zohairy et al.[12] (2003)	Netherlands	Feldspathic	Syntac OptiBond Solo Plus Scotchbond	Tetric flow Nexus 2 RelyX ARC	24h	Bond strength/ Microtensile	Adhesive	+ for OptiBond = for Syntac and Scotchbond
El Zohairy et al.[18] (2004)	Netherlands	Feldspathic	Syntac OptiBond Solo Plus Visio Bond	Tetric flow Nexus 2	1 day, 7 days and 28 days.	Bond strength/ Microtensile	Adhesive	- ou =
Peumans et al.[19] (2007)	Japan	Leucite	Heliobond	Variolink II	24h	Bond strength/ Microtensile	Adhesive	=
Meng et al.[20] (2008)	Japan	Leucite	Heliobond	Variolink II	24h or 10,000 cycles of TC.	Bond strength/ Microshear	Mixed	-

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Passos et al.[21] (2008)	Brazil	Feldspathic	Scotchbond	Variolink II	Immediate or 12,000 cycles of TC+ 50 days of storage	Bond strength/ Microtensile	Mixed	-
Lise et al.[22] (2015)	Brazil	Lithium disilicate	ExciTE F DSC	Variolink II Multilink Automix RelyX Unicem 2	24h	Bond strength/ Microshear	Adhesive	=
Elsayed et al.[23] (2017)	Germany	Lithium disilicate	Scotchbond Universal; OptiBond XRT; All Bond Universal; Prime e Bond NT	Variolink Esthetic DC RelyX Ultimate NX 3 Calibra Esthetic	3 days, 30 days and 7500 cycles of TC or 150 days 37,500 cycles of TC	Bond strength/ Tensile	Cohesive	=
Murillo-Gómez et al.[13] (2017)	Brazil	Lithium disilicate	Single Bond Plus; Scotchbond Universal	RelyX Ultimate	24h or 6 months	Bond strength/ Microshear	Cohesive	=
Ataol and Ergun[24] (2018)	Turkey	Lithium disilicate Zirconia-reinforced lithium silicate	Clearfil Universal Bond	Clearfil Majesty ES-2	24h or 5,000 cycles of TC	Bond strength/ Shear	Adhesive	-
Romanini-Junior et al.[16] (2018)	Brazil	Lithium disilicate	XP Bond; Scotchbond Universal	SureFil SDR Flow	24h and 12 months	Bond strength/ Microshear	Adhesive	+ in 24h - or = in 12 months
Barbon et al.[17] (2019)	Brazil	Feldspathic	Adper Single Bond 2	RelyX Veneer and 3 experimental resin cements	Immediate	Bond strength/ Microtensile	Mixed	= or + depending on resin cement.
						Flexural strength/ Biaxial	Fracture	= or - depending on resin cement.
Chen et al.[25] (2019)	China	Lithium disilicate	Single Bond Plus; All Bond Universal	RelyX Veneer Clearfil AS Luting RelyX Unicem	24h or 20,000 cycles of TC and 120 days of storage	Bond strength/ Shear	Mixed	+
Murillo-Gómez et al.[26] (2019)	Brazil	Lithium disilicate	Adper Single Bond Plus; Single Bond Universal	RelyX Ultimate	24h	Flexural strength/ Biaxial	Fracture	=
Tribst et al.[27] (2019)	Brazil	Lithium disilicate	Single Bond Universal; Multilink N Primer A and B	Multilink N	24h up to a maximum of 7 days	Fatigue failure load/ Staircase test	Radial crack	=
Südbeck et al.[28] (2021)	Germany	Leucite or Lithium disilicate	Scotchbond Universal	Variolink Esthetic DC RelyX Ultimate	24h or 6 months	Bond strength/ Microtensile	Mixed	-

* + the use of adhesive was favorable to the outcome; - the use of adhesive was unfavorable to the outcome; = the use of adhesive was not altered to the outcome.
TC= thermocycling.

Discussion

The longevity of the adhesion of resin materials to glass-ceramics is associated with a correct treatment of the ceramic surface[29]. Conventional surface treatment involving HF etching and silanization is well established for glass-ceramics[30,31]. However, modifications have been suggested, such as the application of an adhesive after ceramic surface treatment[15]. In addition, based on the data of this review, this additional step does not seem to improve the adhesive and mechanical behavior of glass-ceramics, since the results in most studies were similar or worse than conventional treatment.

Only four studies showed favorable results from the adhesive application for the bond strength outcome[12,16,17,25]. However, the results of El Zohairy et al.[12] (2003) were only favorable for the OptiBond adhesive, while the results for the Syntac and Scotchbond adhesives were similar to the control, with the authors justifying this fact due to the greater filler content in the OptiBond adhesive. The results found by Romanini-Junior et al.[16] (2018) were in favor of adhesive layer application only when tested after 24h, which was not maintained after 12 months of storage, since the hydrophilic characteristic of the adhesives used favors hydrolytic degradation over time. For Barbon et al.[17] (2019), the adhesive layer application favors the bond strength values when associated with experimental resin cements of higher viscosity, as they facilitate filling in irregularities by HF etching on the ceramic surface.

A common characteristic among the studies in which the adhesive layer application was unfavorable to the outcome[20,21,28] is the hydrophilicity of the adhesives used. The adhesives are present in hydrophobic or hydrophilic form, with the latter being characterized by its affinity for water. Water absorption is influenced by the material's affinity for water and by the amount of hydroxyl groups (OH) in the resin matrix , which form hydrogen bonds with water, favoring water absorption and consequently worsening adhesion over time[32]. In this sense, applying an adhesive with hydrophilic properties on the ceramic surface can make the adhesive interface more susceptible to hydrolytic degradation over time.

It is important to highlight that restorative materials are exposed to the presence of moisture, chewing loads, changes in temperature and pH in the oral environment[33]. These factors tend to degrade the adhesive interface over time. In this sense, it is important that this degradation is simulated in *in vitro* studies through the storage and/or thermocycling of the specimens[34]. Some kind of aging protocol was used in most of the included studies in the present review, demonstrating the authors' concern in this regard. However, especially in studies that showed no influence of the adhesive application after ceramic surface treatment, the specimens were not subjected to aging protocols, and consequently the results may have been overestimated. Therefore, they must be interpreted with caution.

In addition, when it comes to adhesion tests, it is known that micro tests are the most reliable since they tend to include a smaller number of defects in the substrate or at the bond interface[35]. Most of the included articles adopted microshear or microtensile tests, demonstrating the authors' concern with this point. In observing the overall findings, the adhesion test methodology did not influence the results' trends. Another important point in relation to adhesion studies is the presence of a careful analysis regarding the types of failure found (adhesive, mixed or cohesive) and their relationship with the findings[34]. In this context, all included studies presented such analyzes.

Mechanical outcomes were only evaluated by 3 studies[17,26,36]. Flexural strength data were obtained from the biaxial tests using ceramic discs resin-cement coated[17,26]. The data regarding fatigue failure load data come from simplified restorations (ceramic discs cemented on a supporting substrate) subjected to cyclic fatigue[36]. In both studies the adhesive application did not improve the mechanical outcomes, yet more studies employing these methodologies are encouraged due to the scarce available evidence.

Universal adhesives (UAs) were the most used adhesives in the studies (Table 2). UAs were launched with the purpose of simplifying the adhesive technique, and can be used on dental substrates with or without acid etching, in addition to promoting adhesion to different substrates due to the presence of methacryloyloxydecyl dihydrogen phosphate (MDP) monomers and silane incorporation in their composition[37-40]. In silane-containing UAs, manufacturers suggest that the adhesive can replace silane application after HF etching on glass-ceramics[16]. However, studies show that the amount of silane present in the UAs would not be enough to replace the application of a silane layer[9,16,41]. One of the inclusion criteria required in the present review was that there were comparison groups (HF + Silane) X (HF + Silane + Adhesive); thus, studies which only applied UAs were not included. In this sense, application of silane-containing UAs would add an additional layer of silane, but there was no improvement in the bond strength values[16,24].

Adhesive technique is an extremely sensitive procedure and subject to operator experience and skill[42,43]. Therefore, the inclusion of additional steps such as the adhesive application after ceramic surface treatment can make the procedure even more complex and subject to operator errors. In addition, in view of most of the available evidence demonstrating that application of an adhesive layer was unfavorable or without influence on the evaluated outcomes, this may be a dispensable step.

The aim of the present review was to perform a qualitative synthesis of the studies available in the literature, but a quantitative synthesis and risk of bias analysis of the studies were not performed. In addition, all included studies were laboratory studies, since only this design is able to evaluate adhesive outcomes in an isolated form. Clinical studies may evaluate the survival rate of dental restorations with a higher level of evidence; however, such an outcome may be influenced at the same time by cyclic loads, wear and/or parafunction habits, which may generate cracks and fractures. Therefore, extrapolating the results of *in vitro* studies to the clinical practice should be done with caution. Another important point is how the application of an adhesive could influence the adaptation of indirect ceramic restorations, however the lack of evidence on the subject makes the discussion difficult. The absence of clinical studies on the subject until this time impairs being able to indicate the application of an adhesive after surface treatment of glass-ceramics. In this sense, the conduction of clinical studies and studies of mechanical properties within the theme is suggested.

In conclusion, most of the evidence available in the literature demonstrates that the adhesive application after surface treatment does not improve the adhesive or mechanical behavior of glass-ceramics. However, the literature still lacks clinical studies on the subject.

Conflict of Interest

None

Data availability

Datasets related to this article will be available upon request from the corresponding author.

Author Contribution

Helder Callegaro Velho: Conceptualization, data curation, formal analysis, methodology, writing – original draft;

Pablo Soares Machado: Conceptualization, data curation, formal analysis, methodology, writing – review & editing;

Lucas Saldanha da Rosa: Formal analysis, methodology, writing – review & editing;

Catina Prochnow: Formal analysis, methodology, writing – review & editing;

Jatyr Pisani Proenca: Conceptualization, supervision, formal analysis, data curation, writing – review & editing;

All authors actively participated in the manuscript's findings and have revised and approved the final version of the manuscript.

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