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Effect of Surface Treatments on the Bond Strength of Computer-aided Design and Computer-aided Manufacturing Lithium Disilicate to Restorative Materials: A Systematic Review

Keywords

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ABSTRACT

Objectives: Using computer-aided design and manufacturing (CAD-CAM) technology in restorative dentistry increased the application of lithium disilicate (LD) materials. The bond strength to core and repairing materials is crucial in the restoration's longevity. This systematic review evaluates the shear bond strength (SBS) of CAD-CAM-LD restorative materials to other materials using different surface treatments. Methods: An electronic literature search was performed through PubMed/Medline, Embase, Web of Science, Scopus, and Google Scholar. Studies were selected based on specific criteria. The risk of bias was assessed using the Joanna Briggs Institute Critical Appraisal Checklist for Quasi-Experimental Studies. Results: Eleven studies were included, primarily investigating composite resin as the repair material. SBS values ranged from 0.82 to 32.96MPa, with the highest values observed for IPS e.max-CAD subjected to silicon carbide polishing, hydrofluoric acid (HF) etching, and silane application. For core materials, the highest SBS was reported for HF-treated IPS e.max-CAD bonded to tribochemically coated titanium and air-abraded zirconia, with SBS values ranging from 5.88 to 34MPa. Conclusions: This review indicates that HF etching combined with silane application is the most effective method for improving bond strength in CAD/CAM-LD restorations. Applying surface treatments to both the core material and CAD/CAM-LD can further enhance bond strength.

INTRODUCTION

Computer-aided design and manufacturing (CAD/CAM) has become a rapidly advancing technological facet in dentistry. Many studies indicate that CAD/CAM technology offers several benefits, including reduced clinical appointments, chairside duration, laboratory procedures, and polymerization shrinkage[1-6]. Furthermore, the adoption of uniform industrial blanks and blocks markedly mitigates the potential for material deficiencies during both the fabrication process and subsequent clinical application[7].

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In contemporary dentistry, CAD/CAM lithium disilicate (LD) ceramic restorations have achieved widespread acceptance and are increasingly referenced in recent literature[6,8,9]. CAD/CAM-LD materials have become the second most commonly used material for single restorations[6,8-10]. The establishment of a durable, long-term bond between esthetic restorations and their underlying core structures within the oral environment is essential for achieving the desired longevity and functional stability of these restorations. Due to the relatively low flexural strength of most silicate ceramics, conventional cementation methods are generally inadequate, necessitating adhesive bonding to ensure the stability of the ceramic framework[10-12]. Adhesive bonding offers considerable advantages over traditional cementation, including superior bond strength (BS), enhanced restoration stability, and improved esthetic outcomes[10,11].

An adhesive protocol, involving the application of bonding agents and specific surface treatments, is essential to reinforce the bond between LD restorations and the underlying tooth structure or core materials. This protocol improves the stability, longevity, and resistance to dislodgment or fractures under functional loads. Adhesive bonding compensates for the mechanical limitations of LD by forming a strong micromechanical interlock and chemical adhesion, which more effectively distributes stress across the ceramic surface. Surface treatments, such as hydrofluoric acid (HF) etching and silane application, modify the LD surface to increase its wettability and surface area, further enhancing adhesive bond strength[11,13,14].

Failures in CAD/CAM-LD restorations are often attributed to bonding degradation, material fractures, and improper surface treatments. Bonding integrity may deteriorate over time due to thermal cycling, mechanical stresses, and environmental exposure, thereby undermining the long-term success of restorations[15-18]. All ceramic restorations made of LD are always susceptible to failure due to fractures, cracks, or chipping, especially when subjected to heavy occlusal forces or parafunctional activities[15-17].

Replacing damaged ceramic restorations is not universally optimal, as the replacement process may damage the tooth structure, potentially causing trauma and incurring significant time and financial costs for both clinicians and patients. Consequently, direct intraoral repair of fractured restorations has emerged as an essential, cost-effective alternative[17]. A central requirement for the success of this reparative approach is establishing a durable bond between the original LD restoration and the repair material[15,17,19-22]. To achieve an optimal repair interface, various mechanical treatments—such as sandblasting (air-particle abrasion), laser irradiation, bur roughening, and tribochemical silicoating—and chemical surface treatments, including acid etching, glaze layering, and silane application, are employed to enhance the BS of CAD/CAM materials, creating a robust and enduring bonding interface[17,23].

The primary objective of this review was to systematically evaluate the shear bond strength (SBS) of CAD/CAM-LD restorative materials (either chairside or labside) to other restorative materials to furnish clinicians with insightful considerations for refining their choices of core and/or repairing materials in the context of LD restorations. Additionally, an exhaustive analysis was conducted to assess potential determinants influencing this bonding strength, encompassing factors such as surface pretreatments.

METHODS

In compliance with the guidelines stipulated by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[24], this review was prepared and registered with the International Prospective Register of Systematic Reviews (PROSPERO: CRD42023470450).

The study reviewed relevant research based on specific criteria. It encompassed research where dental restorations were constructed using CAD/CAM-LD restorative materials (population), and interventions encompassed three materials' groups (composite, metal, and ceramics) bonded to LD and different treatments such as acid etching, sandblasting (air abrading), tribochemical silica coating, bur roughening, and laser treatment (intervention). The primary focus was assessing the SBS between CAD/CAM-LD restorations and other restorative materials namely composites, ceramics, and metals as core and/or repairing materials, and comparing the influence of different surface treatments (outcome).

Studies that primarily examined SBS between CAD/CAM materials and dentine, cement without involving any core materials or centered on dentures, fixed partial dentures, implant abutments, and posts were excluded. Systematic reviews, meta-analyses, literature reviews, case reports, and letters to editors were also excluded from consideration.

An electronic search was conducted utilizing prominent databases up to July 28th, 2023, including PubMed, Google Scholar, Embase, Scopus, and ScienceDirect. A search update was performed on June 20, 2024. The search was limited to English journal publications and literature, without imposing any limitations on the publication year. For each database, tailored keywords and search queries were employed as presented in Table 1. Also, a manual search was performed within the compiled list of included studies to identify any potentially overlooked articles.

Endnote X9 (Clarivate) was utilized for citation management. After eliminating duplicated papers using the "Find Duplicates" option in Endnote X9 and scanning found duplicates by R.S., the title and abstract of all articles were evaluated based on PICO and the eligibility criteria by two evaluators independently (R.S. and S.E.). In instances of discrepancies, a third reviewer (R.R.) was consulted to achieve a consensus. Following this, the complete texts of eligible studies were reviewed by two independent assessors (R.S. and S.E.). If disagreements arose, a resolution was attained through consensus involving a third investigator (R.R.).

Table 1. The strategy for boolean search.

Database	Keywords	Results
PubMed	(“CAD-CAM”[All Fields] OR “Computer-Aided Design”[MeSH Terms]) AND (“lithium disilicate”[All Fields] OR “dental ceramics”[All Fields])	953
Google Scholar	ALL (“thermal aging” AND (“CAD-CAM” OR “Computer-Aided Design”) AND (“lithium disilicate” OR “dental ceramics”))	576
Embase	(‘cad-cam’/exp OR ‘cad-cam’ OR ‘computer-aided design’/exp OR ‘computer-aided design’) AND (‘bond’/exp OR ‘bond’ OR ‘bond strength’/exp OR ‘bond strength’) AND (‘lithium disilicate’/exp OR ‘lithium disilicate’ OR ‘dental ceramics’/exp OR ‘dental ceramics’)	154
Scopus	TITLE-ABS-KEY ((“cad-cam” OR “computer-aided design”) AND (“bond strength” OR “bond”) AND (“lithium disilicate” OR “dental ceramics”))	131
ScienceDirect	“Lithium disilicate” AND “bond strength”	715

The data extraction process involved independent extraction from the full text of the included articles by two reviewers (R.S. and S.E.) achieving a substantial inter-selector agreement rate of 96%. Subsequently, a third reviewer (R.R.) meticulously reviewed the extracted data. These data encompassed various aspects including bibliographic details (authors and publication dates), study objectives, the specific CAD/CAM systems and the restorative materials they were bonded to, manufacturing techniques, software programs utilized, scanning methodologies, types of restorations or CAD/CAM block dimensions, sample sizes, surface treatments, measurement techniques, and the observed outcomes.

The assessment of the risk of bias was conducted by two reviewers (R.S. and S.E.) resulting in a commendable inter-rater agreement of 90%. The evaluation employed the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Quasi-Experimental Studies. In the event of any disparities between the two reviewers, a constructive resolution was achieved through consensus, incorporating the perspective of a third reviewer (R.R.). The evaluation entailed a comprehensive scrutiny based on a set of criteria. This encompassed evaluating the studies for the clarity and relevance of their objectives, the explicit identification of CAD/CAM systems and restorative materials, and transparency regarding fabrication methods, software, and scanning technology utilized. Additionally, it assessed whether the studies considered specific restoration types or CAD/CAM block sizes, and if their sample sizes were adequate for drawing meaningful conclusions. The analysis included clarification of the presence and impact of surface treatments, meticulous scrutiny of measurement methodologies for surface analysis and SBS assessment in terms of rigor and appropriateness, evaluation of the consistency and reliability of outcome measurements, and the utilization of suitable statistical analysis techniques.

RESULT

Figure 1 demonstrates the process of selecting studies, portrayed through the PRISMA flow chart. After applying specific criteria, 11 articles were considered for inclusion in this review (*Figure 1*). Most of these investigations (37%) were published in 2023 (4 studies)[17,18,25,26].

We analyzed the findings of this review in two main groups: 1) CAD/CAM-LD bonded to other materials as repairing materials; 2) CAD/CAM-LD bonded to other materials as core.

1) CAD/CAM-LD BONDED TO OTHER MATERIALS AS REPAIRING MATERIALS

Tables 2 and 3 summarize key findings from studies examining the SBS of CAD/CAM-LD bonded to repair materials. This group includes 4 studies[17,25,27,28], with IPS e.max CAD being the most frequently studied LD (75%, 3 studies) [25,27,28]. Composite resin was the only material used for repairing CAD/CAM-LD, with SBS values ranging from 0.82 to 32.96 MPa. The lowest SBS was observed with IPS e.max CAD bonded to a self-adhering flowable composite resin, treated with diamond bur roughening and silane application [28]. However, the highest SBS was achieved with IPS e.max CAD polished using 320, 400, 1,200, and 3,000-grit silicon carbide (SiC) paper and 0.5 µm grit diamond paste, followed by hydrofluoric acid (HF) etching, and the application of silane and Single Bond Universal[27].

2) CAD/CAM-LD BONDED TO OTHER MATERIALS AS CORE

Tables 4 and 5 present a summary of key findings from studies investigating the SBS of CAD/CAM-LD when bonded to core materials. Seven studies were analyzed and divided into two main groups based on the bonding method (1 study used both methods)[29]: cementation (6 studies)[18,21,22,26,29,30] and fusion ceramic techniques (2 studies)[29,31].

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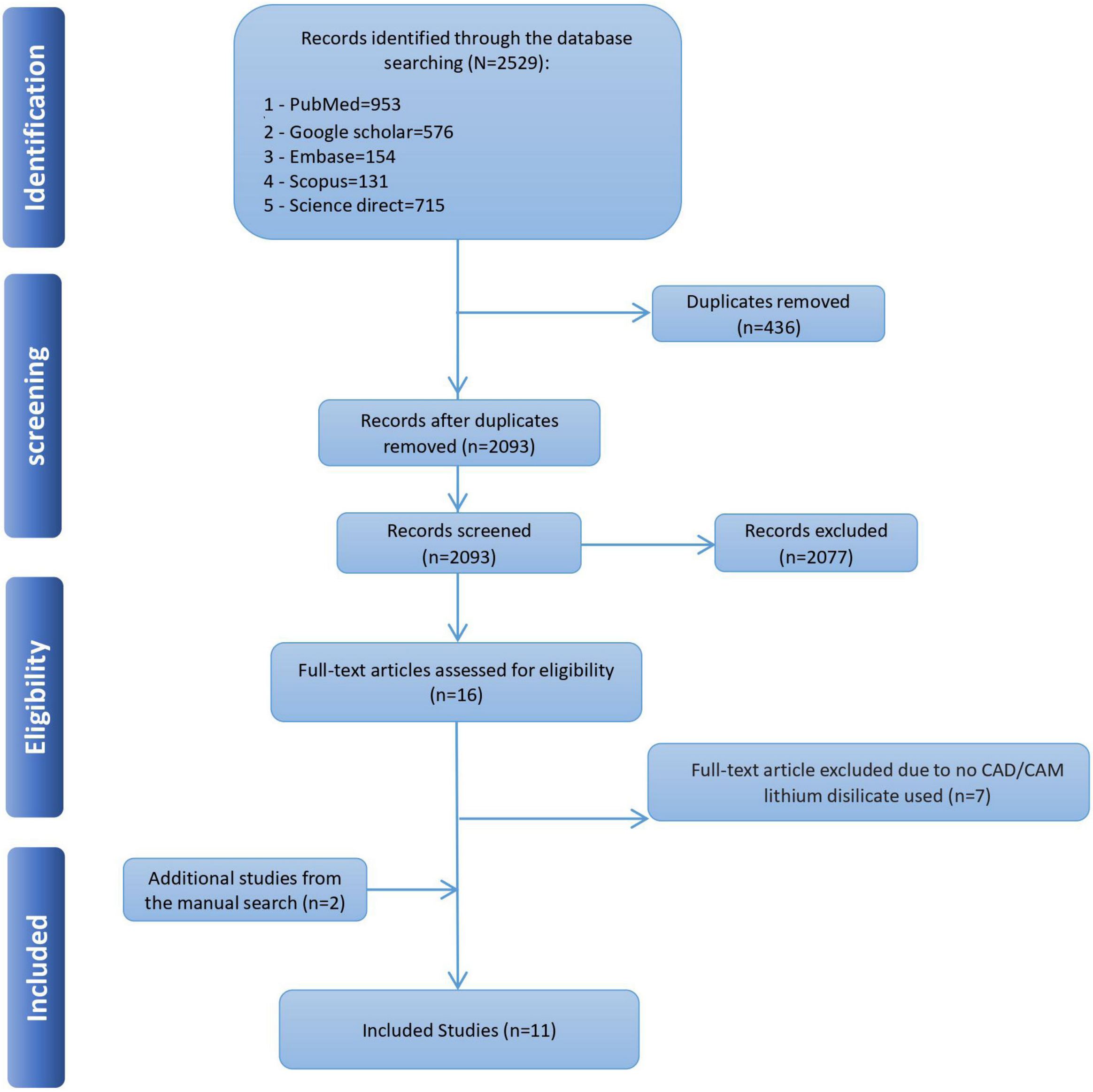

Figure 1: The graphical representation illustrating the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart. PRISMA flow illustration representing the searches of the database, summary screening, and analysis of the full text for the present systematic review.

For subgroup analysis, the studies were categorized by core material type: composite, metal, and ceramic. In the fusion ceramics group, zirconia was the only core material studied. In the cementation group, composite, titanium, and zirconia were the primary materials analyzed. The SBS of LD to composites ranged from 5.88 to 20.07 MPa, for titanium from 9.13 to 20.43 MPa, and for zirconia from 0.4 to 34 MPa.

The highest SBS for LD bonded to composite was achieved using IPS e.max CAD, which was surface-treated with HF, ultrasonically washed, and thermally aged for 5000 cycles[26]. It was bonded to a composite resin using Monobond S and cemented with Multilink Automix, a dual-cure adhesive cement. Conversely, the lowest SBS for the composite was also observed with IPS e.max CAD, but it was surface-treated with phosphoric acid and Monobond Etch and Prime, thermally aged for 20,000 cycles, and bonded to the same material as the highest SBS[26].

For titanium, the highest SBS was noted with IPS e.max CAD that was polished, glaze layered, etched with HF, and bonded to a tribochemically coated titanium core using Monobond Plus and cemented with Panavia 21[18]. The lowest SBS was associated with IPS e.max CAD that was not surface-treated and cemented with Multilink Hybrid to untreated titanium[30].

In the ceramic group, the highest SBS was obtained with IPS e.max CAD surface-treated with HF, bonded to an air-abraded zirconia core using Clearfil Photo Bond, and cemented with Panavia V5[22]. The lowest SBS for ceramics was observed with untreated IPS e.max CAD bonded to an air-abraded zirconia core using Clearfil Porcelain Bond Activator and Panavia V5, and thermocycled for 20,000 cycles [21].

The outcomes of the risk of bias assessment conducted using the JBI Critical Appraisal Checklist for Quasi-Experimental Studies for the studies encompassed within the analysis are presented in

Table 2. Summary of findings of included studies that analyzed repairing bond strength of CAD/CAM-LD.

Bonded materials subgroups	Author/ year/ ref	Type of Study	Aim of study	CAD-CAM material	Ceramic primer	Bonding agent	Bonded materials	Intervention	LD bonding Performance (Mean SBS)	Outcomes
Composite	Aladağ et al. 2023[1]	In vitro	SBS evaluation of CAD/ CAM ceramics repaired with composite resins using different surface treatments combined with laser irradiation	Y-TZP (Upcera ST, Upcera, China) ZLS (Vita Suprinity, Vita Zahnfabrik, Germany) LD-LAS (Nice block, Institut Straumann, Switzerland)	Clearfil Ceramic Primer Plus, Kuraray, Japan	Single Bond Universal Adhesive, 3 M ESPE, USA	Composite resin (Estelite Sigma Quick, Kuraray, Japan)	Er:YAG laser Nd:YAG laser HF Er:YAG +HF Nd:YAG +HF 50 µm Al_2O_3 particle sandblasting	No treatment LD-LAS	7.08±0.39 MPa
									Er:YAG LD-LAS	7.18±0.38 MPa
									Nd:YAG LD-LAS	6.71±0.41 MPa
									HF etching LD-LAS	16.99±0.52 MPa
									HF + Er:YAG LD-LAS	22.43±0.70 MPa
									HF+ Nd:YAG LD-LAS	22.54±0.72 MPa
									Sandblasting LD-LAS	8.74±0.63 MPa
	Fathpour et al. 2023[2]	In vitro	SBS evaluation of LD and composite resin using universal bonding under different surface treatments	IPS e.max CAD (Ivoclar Vivadent, Amherst, NY, USA)	NA	ALL-Bond Universal, Bisco, USA	Composite resin (Gradia anterior composite in A2 color, GC, Japan)	HF Bur roughening +HF Bur roughening +HF+ Silane Sandblasting Sandblasting +HF Sandblasting +HF +Silane	HF	6.65±2.78 MPa
									Bur roughening +HF	8.55±2.69 MPa
									Bur roughening +HF+ Silane	8.48±2.13 MPa
									Sandblasting	3.12±1.66 MPa
									Sandblasting +HF	7.94±2.39 MPa
									Sandblasting +HF +Silane	10.03±2.46 MPa
	Yao et al. 2017[3]	In vitro	SBS evaluation between LD and composite resin after silane pretreatment	E-max CAD (Ivoclar Vivadent, Schaan, Liechtenstein)	RelyX Ceramic Primer; 3M ESPE, St Paul, MN, USA	ALL-Bond Universal, Bisco, USA Adhese Universal; Ivoclar Vivadent Clearfil Universal Bond; Kuraray Noritake Dental, Tokyo, Japan Single Bond Universal; 3M ESPE	Composite resin (Charisma; Heraeus Kulzer, Hanau, Germany)	Surface polished using 320, 400, 1,200, 3,000-grit SiC paper Soft clothing using 0.5 µm grit diamond paste HF HF+ Silane	ABU	17.54±3.14 MPa
									ABU+ Silane	24.93±3.37 MPa
									ADU	17.77±2.37 MPa
									ADU+ Silane	27.29±3.62 MPa
									CUB	14.25±1.65 MPa
									CUB+ Silane	23.24±2.62 MPa
									SBU	18.14±2.63 MPa
									SBU+ Silane	32.96±2.91 MPa
	Erdemir et al. 2014[4]	In vitro	SBS evaluation of LD and self-adhering flowable composite resin under different surface treatments	IPS e.max CAD (Ivoclar-Vivadent, Schaan, Liechtenstien)	NA	NA	Composite resin (self-adhering, flowable composite resin, Vertise Flow, Kerr Corp, Orange, CA, USA)	Surface polished using 400, 600, 800, and 1000-grit SiC paper Tribochemical silica coating +Silane HF +Silane Er:YAG laser irradiation +Silane Diamond bur roughening +Silane	No treatment	1.36±1.86 MPa
									Tribochemical silica coating +Silane	5.36±2.58 MPa
									HF +Silane	6.82±4.4 MPa
									Er:YAG laser +Silane	0.91±1.48 MPa
									Diamond bur roughening +Silane	0.82±0.48 MPa

Abbreviations: ABU, all bond universal; ADU, adhesive universal; CAD/CAM, computer-aided design and computer-aided manufacturing; CCP, clearfil ceramic primer plus; Cp Ti, commercially pure titanium; CUB, clearfil universal bond; Er:YAG, erbium-doped yttrium aluminum garnet; HF, hydrofluoric acid; LD, lithium disilicate; LDC, lithium disilicate glass-ceramic; LD-LAS, lithium disilicate–strengthened lithium aluminosilicate glass-ceramic; LT, long-term; MBP, monobond plus; MEP, monobond etch and prime; Nd:YAG, neodymium-doped yttrium aluminum garnet; PA, phosphoric acid; SBS, shear bond strength; SiC, silicon carbide; ST, short-term; US, ultrasonic washing; W, washing only; Y-TZP, yttrium oxide partially stabilized tetragonal zirconia polycrystal; ZLS, zirconia-reinforced lithium silicate ceramic.

Table 3. Supplementary materials regarding the studies analyzing repairing bond strength of CAD/CAM-LD.

Bonded materials subgroups	Author/ year/ ref	Specimens		CAD-CAM Method			Surface Assessment	Bond Strength Assessment
		Number of specimens	Restoration type	CAD-CAM Method	Scanner brand	Software program	Surface evaluation	Method of measurement
Composite	Aladağ et al. 2023[1]	147	2.5mm thickness specimens	Milling FOR Zirconia	NA	Zirconia were esigned with Autodesk, Autodesk GmbH, Germany CAD-CAM software (Exocad DentalCAD, Exocad GmbH, Germany)	NA	Using a UTM at a 0.5 mm/min crosshead speed
	Fathpour et al. 2023[2]	72	8 mm ×8 mm × 3 mm thickness LD plates	NA	NA	NA	NA	Using a UTM at a 0.5 mm/min crosshead speed
	Yao et al. 2017[3]	120	Specimen in 8 mm length 9.7 mm width 9.2 mm height	NA	NA	NA	SEM Light microscopy	Using a UTM at a crosshead speed of 1 mm/min
	Erdemir et al. 2014[4]	80	6 mm ×4 mm × 3 mm thickness ceramic plates	NA	NA	NA	A Universal Scanning Probe Microscope	Using a UTM at a crosshead speed of 1 mm/min

Abbreviations: LD, lithium disilicate; NA, not available; SEM, scanning electron microscope; UTM, universal testing machine.

Figure 2. Eight of the included studies underwent an assessment, demonstrating a low susceptibility to bias across at least seven specified criteria *(Figure 2)*.

Due to high heterogeneity and the lack of sufficient studies providing essential data, it was not possible to conduct a meta-analysis.

DISCUSSION

The present review analyzed 11 studies on the SBS of CAD/CAM-LD restorative materials to other restorative materials using different surface treatments.

We found high heterogeneity regarding the materials examined for bonding to CAD/CAM-LD. The assessment of SBS between composite resin and CAD/CAM ceramic materials was the predominant focus, constituting 45.5% of the total research endeavors[17,25-28]. Additionally, 80% of these studies used composite resin as a repairing material for CAD/CAM-LD[17,25,27,28]. This emphasis on SBS assessment can be attributed to the significant role of composite resin in the direct repair process of CAD/CAM-LD ceramics, a subject garnering increased attention in research[15,17,32-36]. Zirconia was the second most studied material, comprising 27.3% of the total research efforts. All these studies investigated zirconia as a core material for CAD/CAM-LD.

High heterogeneity was also observed in surface treatments. Common pre-treatments for glass ceramics typically involve HF etching and the application of silane. The results of this review confirmed that the highest SBS was achieved when LD was etched using HF. Additionally, it appears that surface treatment of both the core materials and the CAD/CAM-LD can increase bond strength.

The emergence of dental CAD/CAM technology has revolutionized dentistry by providing a numerous advantage over traditional dental restorations[4]. By utilizing this technology, dentists can create restorations that are known for their precise fit and natural-looking aesthetics. This approach preserves healthy tooth structure while improving strength and durability, which ultimately reduces the need for invasive procedures and promotes biocompatibility. By creating an appropriate seal, CAD/CAM restorations also reduce sensitivity and are resistant to staining, providing patients with versatile options that increase satisfaction[3,37-44].

However, restorations made from CAD/CAM materials can experience failures. CAD/CAM-LD restorations can fail due to several mechanisms, including fractures, chipping, and debonding[15-18]. To mitigate the risk of these failures, preventive measures are preferable over repair whenever possible. Strengthening the adhesive bond with effective bonding agents and suitable surface treatments can significantly

Table 4. Summary of findings of included studies analyzing SBS of LD to other restorative materials as core materials.

Interfaces	Bonded materials subgroups	Author/ year/ ref	Type of Study	Aim of study	CAD-CAM material	Bonded materials	Intervention				Thermal cycling/ Thermal aging	LD bonding Performance (Mean SBS)	Outcomes
							LD surfaces treatment	Silane/ Primer agent/ Fusion porcelain	Cementation	Core surfaces treatment			
One interface	Ceramics	Çakırbay Tanış et al. 2020[5]	In vitro	SBS evaluation of CAD-CAM veneers to zirconia ceramic cores using resin cement or fusion porcelain	IPS e.max CAD (Ivoclar Vivadent AG, Schaan, Liechtenstein) Cerec Blocs (VITA Zahnfabrik, Bad Sackingen, Germany) Conventional feldspathic ceramic (VITA VM®9; VITA Zahnfabrik, Bad Sackingen, Germany)	Zirconia (APW02 Zir Dental; Aidite, Qinhuangdao, China)	HF	Low-fusion porcelain (Vision Zirkon; Wohlwend AG Dental Manufacturer, Schellenberg, Liechtenstein)	Not applicable in one interface subgroup analysis	Surface polished using 600-grit SiC paper Glaze layer HF after glazing	NA	IPS e.max CAD, fusion porcelain	27.11±7.7 MPa
		Yilmaz-Savas et al. 2016[6]	In vitro	LD CAD-on technique's SBS evaluation to zirconia core under different surface treatments	IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechstenstein)	Zirconia (IPS e.max ZirCAD, Ivoclar Vivadent)	50µm-Al_2O_3 Sandblasting Er:YAG laser Femtosecond laser	A thixotropic glass-fusion ceramic (IPS e.max CAD Crystall/ Connect; Ivoclar Vivadent)	NA	Surface polished using 600-grit SiC paper 50µm-Al_2O_3 Sandblasting Er:YAG laser Femtosecond laser	NA	IPS e.max CAD, No treatment	32.52± 10.15
												IPS e.max CAD, Sandblasting	33.03± 5.05
												IPS e.max CAD, Er:YAG irradiation	31.02± 4.96
												IPS e.max CAD, Femtosecond laser irradiation	36± 3.31
Two interfaces	Composite	Çınar et al. 2023[7]	In vitro	SBS evaluation of CAD-CAM block under different aging protocols after acid etching and surface washing	IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechstenstein) Celtra Duo (Celtra Duo Dentsply, Konstanz, Germany)	Composite resin (Tetric N-Ceram; Ivoclar, Vivadent, Schaan, Liechtenstein)	Surface polished using 600, 900, and 1200-grit SiC paper HF+W HF+US HF+PA MEP+W MEP+US MEP+PA	Monobond S, Ivoclar, Vivadent, Schaan, Liechtenstein	A dual cure adhesive cement (Multilink Automix; Ivoclar Vivadent, Schaan, Liechtenstein)	NA	Thermal aging: (LT (20000 thermal cycles), ST (5000 thermal cycles))	IPS e.max CAD- TS (HF+W)	17.71±0.41 MPa
												IPS e.max CAD- TS (HF+PA)	18.96±0.27 MPa
												IPS e.max CAD- TS (HF+US)	20.07±0.31 MPa
												IPS e.max CAD- TS (MEP+W)	16.08±0.20 MPa
												IPS e.max CAD- TS (MEP+PA)	13.09±0.30 MPa
												IPS e.max CAD-TS (MEP+US)	18.22±0.10 MPa
												IPS e.max CAD- TL (HF+W)	9.48±0.25 MPa
												IPS e.max CAD- TL (HF+PA)	11.84±0.35 MPa
												IPS e.max CAD- TL (HF+US)	13.72±0.19 MPa
												IPS e.max CAD- TL (MEP+W)	7.63±0.27 MPa
												IPS e.max CAD- TL (MEP+PA)	5.88±0.38 MPa
												IPS e.max CAD- TL (MEP+US)	11.55±0.18 MPa
	Metal	Tuncer et al. 2023[8]	In vitro	SBS evaluation of CAD/CAM ceramics and ceramic-like materials to titanium under different surface treatment and cementation materials	IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechstenstein) Vita Suprinity (VITA Zahnfabrik, H. Rauter GmbH & Co. KG, Bad Säckingen, Germany) Vita Enamic (VITA Zahnfabrik, H. Rauter GmbH & Co. KG, Bad Säckingen, Germany)	Titanium (grade V titanium)	Surface polished using a polishing device (Metkon Gripo 2V) Glaze layer HF	Monobond Plus, Ivoclar Vivadent, Schaan, Liechtenstein	Self-curing luting composite (Multilink Hybrid Abutment; Ivoclar Vivadent, Schaan, Liechtenstein) Self-curing adhesive cement (Panavia 21; Kuraray Noritake Dental Inc., Okayama, Japan)	Surface polished using 600, 800, and 1200-grit SiC paper Tribochemical coating	Thermal aging for 5000 cycles	IPS e.max CAD - Panavia 21 - tribochemical coated titanium	20.43 MPa
												IPS e.max CAD - Panavia 21 – Non tribochemical coated titanium	17.52 MPa
												IPS e.max CAD - Multilink hybrid abutment - tribochemical coated titanium	29.11 MPa
												IPS e.max CAD - Multilink hybrid abutment – Non-tribochemical coated titanium	25.61 MPa
		Karaokutan et al. 2022[9]	In vitro	SBS comparison of different surface treatments and luting agents of two ceramics to Cp Ti	IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechstenstein) Celtra Duo (Celtra Duo Dentsply, Konstanz, Germany)	Titanium (Cp Ti)	HF	Monobond Plus Clearfil Ceramic Primer Plus	Self-cure resin-based luting agent (Multilink Hybrid Abutment; Ivoclar Vivadent, Schaan, Liechtenstein) Dual-cure resin-based luting agent (Panavia V5; Kuraray Noritake Dental, Tokyo, Japan)	50 µm airborne-particle abrasion 110 µm airborne-particle abrasion Tribochemical coating	Thermal cycling (5000 cycles, 5°- 55°C)	IPS e.max CAD (No treatment + Multilink Hybrid)	9.13 ± 0.91 MPa
												IPS e.max CAD (50 µm airborne-particle abrasion + Multilink Hybrid)	15.89 ± 1.03 MPa
												IPS e.max CAD (110 µm airborne-particle abrasion + Multilink Hybrid)	15.56 ± 1.46 MPa
												IPS e.max CAD (Tribochemical coating + Multilink Hybrid)	12.89 ± 1.11 MPa
												IPS e.max CAD (No treatment + Panavia V5)	12.6 ± 1.62 MPa
												IPS e.max CAD (50 µm airborne-particle abrasion + Panavia V5)	17.58 ± 1.37 MPa
												IPS e.max CAD (110 µm airborne-particle abrasion + Panavia V5)	18.16 ± 1.3 MPa
												IPS e.max CAD (Tribochemical coating + Panavia V5)	15.43 ± 2.11 MPa
	Ceramics	Komine et al. 2021[10]	In vitro	SBS evaluation CAD-CAM composite or ceramics to zirconia framework after roughening and primer application	Composite resin block (Katana Avencia Block, Kuraray Noritake Dental) IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechstenstein)	Zirconia (Katana Zirconia HT, Kuraray Noritake Dental, Tokyo, Japan)	Surface polished using 600-grit SiC paper HF 50 µm airborne-particle abrasion	Clearfil Porcelain Bond Activator, Kuraray Noritake Dental Clearfil Photo Bond, Kuraray Noritake Dental	Dual-polymerizing resin luting agent (Panavia V5; Kuraray Noritake Dental)	Surface polished using 600-grit SiC paper 50 µm airborne-particle abrasion	Thermal cycling for 0 and 20000 cycles	IPS e.max CAD- No treatment – No priming	8.9 (6.9; 10.5)
												IPS e.max CAD- HF – No priming	11.1 (8.1; 14.4)
												IPS e.max CAD- Air abrasion – No priming	15.1 (12.7; 18.8)
												IPS e.max CAD- No treatment - ACT	10.7 (10.1; 11.6)
												IPS e.max CAD- HF - ACT	10.8 (8.3; 13.2)
												IPS e.max CAD- Air abrasion - ACT	16.7 (13.2; 19.9)
												IPS e.max CAD- No treatment – CPB	11.2 (9.4; 13.3)
												IPS e.max CAD- HF - CPB	13.0 (10.9; 16.3)
												IPS e.max CAD- Air abrasion - CPB	17.3 (14.3; 20.0)
												IPS e.max CAD- No treatment - ACT + CPB	11.7 (10.1; 13.6)
												IPS e.max CAD- HF - ACT + CPB	13.2 (10.9; 16.2)
												IPS e.max CAD- Air abrasion - ACT + CPB	18.9 (13.8; 23.4)
												IPS e.max CAD- No treatment – No priming- 20000 thermocycling	0.8 (0.6; 1.0)
												IPS e.max CAD- HF – No priming- 20000 thermocycling	6.4 (3.7; 9.3)
												IPS e.max CAD- Air abrasion – No priming- 20000 thermocycling	10.8 (8.4; 13.8)
												IPS e.max CAD- No treatment - ACT- 20000 thermocycling	0.4 (0.4; 0.5)
												IPS e.max CAD- HF - ACT- 20000 thermocycling	9.3 (7.7; 10.5)
												IPS e.max CAD- Air abrasion - ACT- 20000 thermocycling	14.4 (12.2; 16.4)
												IPS e.max CAD- No treatment – CPB- 20000 thermocycling	1.8 (0.8; 2.8)
												IPS e.max CAD- HF - CPB- 20000 thermocycling	11.3 (9.8; 13.0)
												IPS e.max CAD- Air abrasion - CPB- 20000 thermocycling	15.4 (13.6; 16.1)
												IPS e.max CAD- No treatment - ACT + CPB- 20000 thermocycling	2.3 (1.0; 3.0)
												IPS e.max CAD- HF - ACT + CPB- 20000 thermocycling	11.8 (8.5; 15.0)
												IPS e.max CAD- Air abrasion - ACT + CPB- 20000 thermocycling	15.8 (12.8; 17.5)
		Çakırbay Tanış et al. 2020[5]	In vitro	SBS evaluation of CAD-CAM veneers to zirconia ceramic cores using resin cement or fusion porcelain	IPS e.max CAD (Ivoclar Vivadent AG, Schaan, Liechtenstein) Cerec Blocs (VITA Zahnfabrik, Bad Sackingen, Germany) Conventional feldspathic ceramic (VITA VM®9; VITA Zahnfabrik, Bad Sackingen, Germany)	Zirconia (APW02 Zir Dental; Aidite, Qinhuangdao, China)	HF	Single Bond Universal Adhesive; 3M GmbH, Neuss, Germany	Resin cement (RelyX Ultimate Clicker; 3M GmbH, Neuss, Germany)	Surface polished using 600-grit SiC paper Glaze layer HF after glazing	NA	IPS e.max CAD, resin cement, No surface treatment	9.82±2.8 MPa
												IPS e.max CAD, resin cement, HF	19.83±6.5 MPa
												IPS e.max CAD, resin cement, Zirconia with glaze layer	10.97±5.9 MPa
		Kimura et al. 2019[11]	In vitro	SBS evaluation of CAD-CAM composite resin and ceramic veneers to zirconia frameworks	CAD/CAM resin-based composite (Katana Avencia Block 12/A2 LT; Kuraray Noritake Dental) IPS e.max CAD A2 C14 (Ivoclar Vivadent, Schaan, Liechtenstein)	Zirconia (Katana Zirconia HT; Kuraray Noritake Dental, Tokyo, Japan)	Surface polished using 600-grit SiC paper HF Airborne-particle abrasion	Clearfil Photo Bond, Kuraray Noritake Dental	Resin-based luting agent (Panavia V5; Kuraray Noritake Dental)	Surface polished using 600-grit SiC paper 50 µm airborne-particle abrasion	Thermal cycling (20,000 cycles, 5°-55°C)	IPS e.max CAD- No treatment	13.8 (10.0; 16.9)
												IPS e.max CAD- No treatment – 20000 thermocycling	0.8 (0.6; 1.0)
												IPS e.max CAD- HF	34.0 (29.3; 38.8)
												IPS e.max CAD- HF– 20000 thermocycling	13.8 (12.4; 17.6)
												IPS e.max CAD- Air abrasion	22.6 (18.8; 29.1)
												IPS e.max CAD- Air abrasion– 20000 thermocycling	0.9 (0.7; 1.0)

Abbreviations: ACT, Clearfil Porcelain Bond Activator; CAD/CAM, computer-aided design and computer-aided manufacturing; CCP, clearfil ceramic primer plus; CPB, Clearfil Photo Bond; Cp Ti, commercially pure titanium; Er:YAG, erbium-doped yttrium aluminum garnet; HF, hydrofluoric acid; LD, lithium disilicate; LDC, lithium disilicate glass-ceramic; LD-LAS, lithium disilicate–strengthened lithium aluminosilicate glass-ceramic; LT, long-term; MBP, monobond plus; MEP, monobond etch and prime; Nd:YAG, neodymium-doped yttrium aluminum garnet; PA, phosphoric acid; SBS, shear bond strength; ST, short-term; US, ultrasonic washing; W, washing only; Y-TZP, yttrium oxide partially stabilized tetragonal zirconia polycrystal; ZLS, zirconia-reinforced lithium silicate ceramic.

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Table 5. Supplementary materials regarding studies analyzing SBS of LD to other restorative materials as core materials.

Interfaces	Bonded materials subgroups	Author/ year/ ref	Specimens		CAD-CAM Method			Surface Assessment	Bond Strength Assessment
			Number of specimens	Restoration type	CAD-CAM Method	Scanner brand	Software program	Surface evaluation	Method of measurement
One interface	Ceramics	Çakırbay Tanış et al. 2020[5]	90 (zirconia specimens) 80 veneers: *40 feldspathic ceramic [Cerec Bloc] *40 LD [IPS e.max CAD]	90 Zirconia square prisms in dimensions of 10 × 5 × 5 mm, and 80 veneer blocks in dimensions of 3 × 3 × 1 mm	Milling (using Cerec inLab MC X5 machine)	NA	3D Builder; (Microsoft Corp., Redmond, WA)	NA	Using a UTM at a crosshead speed of 1mm/min
		Yilmaz-Savas et al. 2016[6]	40 Zirconia 40 LD	12.4 mm×11.4 mm×3 mm zirconia plates 5 mm×2 mm cylindrical lithium disilicate	NA	NA	NA	SEM	Using a UTM at 0.5 mm/ min crosshead speed
Two interfaces	Composite	Çınar et al. 2023[7]	240	2mm thicknesses pieces	NA	NA	NA	SEM	Using a UTM at a 0.5 mm/ min crosshead speed
	Metal	Tuncer et al. 2023[8]	120	12 × 12 × 15 mm titanium specimens 5 × 3 mm cylindrical ceramic sections	Milling (using Yenadent D30 CAM)	NA	Wings 7 CAD program (Dental Wings Inc., Montreal, QC, Canada)	SEM	Using a UTM at a crosshead speed of 1 mm/min
		Karaokutan et al. 2022[9]	160 Cp Ti	Cp Ti Disc10 mm×3 mm Ceramic discs 5mm diameter ×3mm hight	Milling	NA	NA	SEM	Using a UTM at a crosshead speed of 1 mm/min
	Ceramics	Komine et al. 2021[10]	528 zirconia disks 11 mm × 2.5 mm 264 AVE and IEC disks	AVE and IEC disks 8 mm × 2.5 mm (serving as veneer) zirconia disks 11 mm × 2.5 mm	NA	NA	NA	SEM	Using a UTM at a 2 mm/ min crosshead speed
		Çakırbay Tanış et al. 2020[5]	90 (zirconia specimens) 80 veneers: *40 feldspathic ceramic [Cerec Bloc] *40 LD [IPS e.max CAD]	90 Zirconia square prisms in dimensions of 10 × 5 × 5 mm, and 80 veneer blocks in dimensions of 3 × 3 × 1 mm	Milling (using Cerec inLab MC X5 machine)	NA	3D Builder; (Microsoft Corp., Redmond, WA)	NA	Using a UTM at a crosshead speed of 1mm/min
		Kimura et al. 2019[11]	132 zirconia discs 132 8 mm × 2.5 mm discs for veneers	Zirconia disks 11.0 mm × 2.5 mm AVE and IEC veneers	NA	NA	NA	SEM	Using a mechanical testing machine at a crosshead speed of 0.5 mm/min

Abbreviations: Cp Ti, commercially pure titanium; LD, lithium disilicate; NA, not available, SBS, shear bond strength; SEM, scanning electron microscope; UTM, universal testing machine

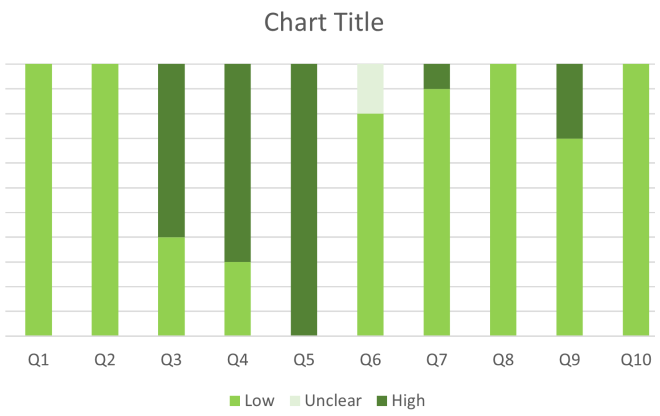

Figure 2: The risk of bias assessment for each domain of included studies.

lower the chances of debonding and fractures. Selecting the appropriate surface treatment can enhance bond strength by creating a micro-retentive surface, which facilitates a strong micromechanical and chemical interlock between the LD and the tooth or core material[30,32,36,45].

Furthermore, while intraoral repair of damaged LD restorations offers a cost-effective and minimally invasive solution, it is generally not as durable or effective as preventive strategies. Repair procedures may involve weaker bond strength than the original adhesive bonding, resulting in a higher risk of subsequent failure. The repaired area may also present esthetic or functional compromises due to the limited bonding area and the potential for residual stress at the fracture site[15,17,20,32,34,36].

Several limitations were observed during the analysis of the studies: 1. Due to high heterogeneity and the low number of studies providing essential data, a meta-analysis was not possible. 2. Two of the studies featured a relatively small sample size, with fewer than 50 specimens[29,31]. 3. The data was highly heterogeneous. A significant challenge was encountered due to the wide variability in the materials, block size and shapes, and type of surface treatments utilized. So, it was difficult to perform a thorough and consistent analysis. 4. Only 3 studies employed software programs for the design process, with specific software tools mentioned, including Wings 7 CAD program[18], AUTOCAD[17], and 3D Builder[29]. Other studies used blocks instead of designing and manufacturing restorations for analyzing BS. They bonded CAD/CAM-LD blocks, disks, slides, or cylindrical-shaped pieces to other material blocks to analyze the BS. As a result, we are not able to analyze the effects of CAD/CAM methods on BS. 5. Limited use of CAD/CAM manufacturing methods was applied. Milling was employed in the manufacturing process of LD restorations or specimens in only 2 of the studies[29,30]. Other studies either did not specify their method or utilized alternative approaches such as cutting their material to size from a block or using entire blocks. 6. The experimental conditions were affected by a wide range of surface treatments, leading to variability in the results and making thorough analysis difficult.

Based on the conducted review, we recommend prioritizing studies with larger sample sizes to improve the comparison of results. Research should be conducted to investigate the effect of sample size on the precision and accuracy of CAD/CAM restorations' BS. Standardizing specimen sizes across studies can minimize variability and enable more robust comparisons since there is no standard sample size to be discussed now. It is also important to evaluate a wider range of CAD/CAM software programs to assess their impact on restoration design and quality.

While this review examined the bond strength between CAD/CAM-LD restorations and various core and restorative materials, future studies should explore the role of adhesion between LD and the natural tooth structure itself. Poor adhesion to enamel or dentin can lead to clinical failures, including debonding, microleakage, and secondary caries, which are critical issues for the long-term success of restorations. Examining adhesive protocols specifically tailored to bond LD with natural tooth surfaces would provide valuable insights into improving overall restoration durability and clinical outcomes.

CONCLUSIONS:

The findings of this review indicate that specific surface treatments, such as hydrofluoric acid etching combined with silane application, are the most effective methods for enhancing bond strength in CAD/CAM-LD restorations. Applying surface treatments to both the core material and CAD/CAM-LD can further increase bond strength.

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT-4o in order to enhance language fluency and improve the clarity of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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