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Effectiveness of self-adhesive resin luting cements in CAD-CAM blocks – A systematic review and meta-analysis

Tatiana Leal Vieira

Dissertação conducente ao Grau de Mestre em Medicina Dentária (ciclo integrado)

Gandra, Setembro de 2022

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Trabalho realizado sob a Orientação de
Professora Dra. Teresa Maria da Costa Pinho

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Eu, **Tatiana Leal Vieira**, declaro ter atuado com absoluta integridade na elaboração deste trabalho, confirmo que em todo o trabalho conducente à sua elaboração não recorri a qualquer forma de falsificação de resultados ou à prática de plágio (ato pelo qual um indivíduo, mesmo por omissão, assume a autoria do trabalho intelectual pertencente a outrem, na sua totalidade ou em partes dele).

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DEDICATÓRIA

Dedico esta tese de mestrado ao meu querido Pai, que tanto admiro, que é um exemplo máximo de superação.

A ti, que nunca tiveste a oportunidade de escolher estudar, como gostarias, e mesmo assim venceste com a tua dedicação e resiliência. Ensinaste-me muito sobre a vida e a persistir nos meus sonhos e ambições. E depois de muito lutar, cheguei aqui, espelhando-me em ti. Se cheguei ao fim deste percurso foi pelo apoio incondicional e amor inabalável que me deste e nunca foi uma opção desistir perante as dificuldades para honrar a oportunidade que tive e que jamais pudeste ter.

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RESUMO

Introdução: Os cimentos resinosos auto-adesivos (SARCs) são amplamente utilizados pelas suas propriedades mecânicas e redução da complexidade dos protocolos de cimentação, ligando-se à superfície dentária sem a necessidade de condicionamento ácido ou sistema adesivo. O sucesso da reabilitação estética e funcional com blocos fabricados por Computer-aided design and computer-aided manufacturing (CAD-CAM) depende da eficácia do cimento utilizado. Existem protocolos adesivos mais eficazes do que outros para cada bloco CAD-CAM. Os SARCs são geralmente de dupla cura, sendo foto-ativados mas também autopolimerizáveis, sofrendo aumento ligeiro do pH, inicialmente ácido, permitindo a auto-adesividade, tornando-se o cimento mais resistente aos fenómenos de hidrólise.

Objectivos: O principal objetivo foi analisar o desempenho mecânico e a eficácia dos SARCs quando utilizados para cimentar blocos CAD-CAM à estrutura dentária.

Materiais e métodos: Foi realizada uma revisão integrativa sistemática com artigos obtidos através da pesquisa nas bases de dados MedLine/PubMed e Science Direct, combinando as palavras-chave na fórmula de pesquisa Booleana: [("dental" ou "tooth") AND ("self-adhesive") AND ("luting" ou "cement")) AND "CAD-CAM") NO ("endodontics" ou "implants")] de 1 de Maio de 2022 a 31 de Julho de 2022.

Resultados: A pesquisa encontrou 199 artigos. Após a aplicação dos critérios de inclusão e exclusão, foram selecionados 31 estudos para avaliação da qualidade. Os Lava Ultimate e Vita Enamic foram os blocos CAD-CAM mais testados. O Rely X Ultimate 2 foi o cimento resinoso mais utilizado, seguido pelo Rely X Unicem, Rely X Ultimate e Rely X U200, e o μTBS MPa foi o teste mais utilizado. A meta-análise confirmou a eficácia dos protocolos SARCs para aderir aos blocos CAD-CAM mas que apesar de serem denominados universais o seu desempenho é dependente do substrato ($P<0,05$).

Conclusões: Os SARCs mostram resultados promissores, mas existem diferenças entre eles. O desempenho da ligação dos SARC aos blocos CAD-CAM está dependente do tipo dos materiais utilizados. Para melhorar a durabilidade e estabilidade das restaurações, deve ser considerada a combinação apropriada de materiais.

Palavras-chave: dental, tooth, self-adhesive, luting, cement, CAD-CAM

ABSTRACT

Introduction: Self-adhesive resin cements (SARCs) are widely used for their mechanical properties and for reducing the complexity of cementation protocols, bonding to the tooth surface without the need for acid conditioning or an adhesive system. The success of aesthetic and functional rehabilitation with ceramic blocks manufactured by Computer-aided design and computer-aided manufacturing (CAD-CAM) depends on the effectiveness of the cement used. There are more effective adhesive protocols than others for each CAD-CAM block. SARCs are generally dual-cured, being photo-activated but also self-cured, suffering a slight increase in the initially acidic pH, allowing self-adhesiveness, and making the cement more resistant to hydrolysis phenomena.

Objectives: The main goal was to analyze the mechanical performance and efficacy of SARCs systems when used to cement CAD-CAM blocks to the tooth structure.

Materials and methods: A systematic integrative review was conducted with articles obtained by searching the MedLine/PubMed and Science Direct databases, combining the keywords in the Boolean search formula: [(”dental” or ”tooth”) AND (”self-adhesive”) AND (”luting” or ”cement”)) AND ”CAD-CAM”) NOT (”endodontics” or ”implants”)] from May 1 of 2012 to July 31 of 2022.

Results: The survey retrieved 199 articles. After applying the inclusion and exclusion criteria, 31 studies were selected for quality assessment. Lava Ultimate and Vita Enamic blocks were the most tested CAD-CAM blocks. Rely X Ultimate 2 was the most widely used resin cement, followed by Rely X Unicem, Rely X Ultimate and Rely X U200, and μTBS MPa was the most used test. The meta-analysis confirmed the efficacy of SARCs protocols to adhere CAD-CAM blocks but that despite being denominated universal, their performance is substrate-dependent ($P<.05$).

Conclusions: SARCs show promising results, but there are differences between them. The performance of SARC binding to CAD-CAM blocks depends on the materials used. The appropriate combination of materials must be considered to improve the durability and stability of restorations.

Keywords: dental, tooth, self-adhesive, luting, cement, CAD-CAM

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ABBREVIATIONS AND ACRONYMS

μm – Micrometer

μSBS - Micro shear bond strength

μTBS - Micro tensile bond strength

CAD-CAM - Computer-aided design - Computer-aided manufacturing

E&R - Etch and rise

FEL – Feldspathic ceramic

HF - Hydrofluoric acid

IDS – Immediate dentin sealing

IG – Internal gap

LDS – Lithium disilicate

MMA – methyl methacrylate

OMP-N – Organic Modified Polymer infiltrated Network

PCC – Parcial ceramic crown

PICN – polymer-infiltrated ceramic network

PMMA – Poly(methyl methacrylate)

RMGI – resin-modified glass-ionomer

RNC – Resin nanoceramic

SB - Single Bond

SBU - Scotchbond Universal

SE - Self-Etch

SARC – Self-adhesive resin cement

ZLS – Zirconia reinforced lithium silicate

INTRODUCTION

CAD-CAM technology in dental medicine is increasingly developing, allowing higher protocol standardization and raising the quality of dental restorations while reducing the production price[1,2] aiming for the use of materials at their highest quality[3], enhancing the outgrowth of highly esthetic and functional restorative materials.[4-6]

This technology has evolved to boost the impression and casting procedures[6-9] supplying easier and quicker indirect restorations, sometimes without the requirement for provisional restorations or dental laboratories, allowing single-visit treatments[4,8,9] with inlays, onlays, veneers, or full-contour crowns fabricated with several alternative materials.[10] Candidate materials may incorporate lithium disilicate glass ceramics, leucite-reinforced glass ceramics, feldspathic glass ceramics, zirconia, resin-matrix composites, polymer-infiltrated resin-ceramics or titanium.[1]

Computer-aided milling of dental materials is changing into a standard dental technique due to high-tech digital technology with image-capturing scanner devices, software, and integrated CAD-CAM systems.[11]

The adhesion of CAD-CAM blocks to the tooth tissues and the cement is crucial for an indirect restoration's clinical success and longevity.[8]

Luting cements are categorized according to the adhesion strategy, which includes the conventional composite resin cement combined with an etch-and-rinse (E&R) adhesive system, the self-conditioning composite resin cement associated with self-adhesive (SE) adhesive systems, and self-adhesive composite resin cement (SARC).[12] Adhesive composite resin cement exhibit good biocompatibility and marginal integrity, low microleakage,[6] mechanical quality ,and esthetic properties, being the most commonly used cement for the bonding of a restoration.[13]

The introduction of SARCs at the beginning of the 21st century as a revolutionary and time-sparing clinical protocl, aimed to allow aneasier-to-handlee luting step.[14]

SARCs protocols eliminate preliminary steps for the surface treatment of the joint substates,[15,16] and bonding to an unconditioned tooth surface, without pretreatment with an acid or adhesive, with theoretically similar bond strength to other established adhesive systems.[17] However, for better adhesion, mild acids can be used to remove or modify the tooth's smear layer[18], but in systems where the smear layer is modified rather than removed, the bond strength was reported to be lower.[17]

To ensure bond strength, air-polishing devices are reported to increase the roughness of dental hard tissues and restorative materials[9]. The first generation of dual-cured SARCs demand surface treatment, sandblasting, and silanization, but recently silane-containing SARCs were released on the market without the need for the silanization step.[15] SARCs chemical composition is based on methacrylate monomers modified by carboxylic or phosphoric acid groups, simultaneously demineralizing and infiltrating dentin and enamel, without the need for separate etch and bonding steps, forming micromechanical and chemical bonding by interaction with the calcium ions of the tooth substrate. After mixing, phosphoric acid groups react with the tooth hard tissue and basic fillers in the luting material (cement reaction), thus forming a bond. Parallel to the cement reaction, polymerization of the methacrylate monomers is initiated (radical polymerization). While the material sets, the acid groups are neutralized, turning the behavior material's hidrophilic to hydrophobic.[14,16]

Simpler and more straightforward, professionals must know that problems can occur during cementation procedure. Lack of polymerization efficiency whith potentially releasing unreacted cytotoxic and genotoxic monomers[13] provoque expansion of the cement layer with polymerization shrinkage strain and high stresses caused by hygroscopic expansion which can lead to crack formation and restoration failure.[16,18] An evenly distributed cement layer with low internal gap values (IG) is essential for the correct seating and better mechanical properties, but also the low space volume of the cement and the porosities volume inside the luting agent.[5] Factors like the mixing method of the cement or the particle size might amplify the formation of porosities.[5] Furthermore, differences in humidity, pH, and temperature of the oral cavity cause changes in dental materials.[19]

The bond strength of ceramic to tooth structure also depends on the type of ceramics, resin-matrix cement, the functional monomer used, and on patient-related factors like dentin thickness, occlusal loading, dental age, and oral hygiene .[17]

OBJECTIVES

The main objective of this systematic review was to analyze the mechanical performance and efficacy of self-adhesive resin-matrix cement systems when used to cement CAD-CAM blocks to the tooth structure. A secondary goal was to compare the performance of self-adhesive resin-matrix cements with conventional resin-matrix cements.

MATERIALS AND METHODS

The review followed the preferred reporting items for systematic reviews and meta-analysis (PRISMA) 2020 recommendations.[20] The population, intervention, comparison, and outcome (PICO) question was: "Are the self-adhesive resin-matrix cements efficient to cement CAD-CAM blocks to tooth structure?" The CAD-CAM blocks constituted the population. The intervention was defined as the self-adhesive resin-matrix cement used for cementation. The comparison was made between each luting cement to find intrastudy and interstudy differences in the mechanical performance, and between them and the conventional resin-matrix luting cements. The adhesive efficiency was the outcome.

Databases and search strategy

Bibliographic research was carried out in MedLine/PubMed, with the keywords conjugated in the Boolean search formula: ("dental" [All Fields] OR "tooth" [MeSH Terms]) AND (("self-adhesive" [All Fields]) AND ("luting" [All Fields] or "cement" [All Fields])) AND "CAD-CAM" [All Fields] NOT ("endodontics" [MeSH Terms] OR "implants" [All Fields]) and in Science Direct the keywords combined in the formula ("dental" or "tooth") AND ("self-adhesive") AND ("luting" or "cement")) AND "CAD-CAM") NOT ("endodontics" or "implants").

Inclusion and exclusion criteria

Inclusion criteria were the English language, research articles published in the last ten years, and articles with accessible full text. Clinical cases, encyclopedia articles, duplicate articles, and articles published before 2012 or not addressing the theme of the study were exclusion criteria.

Preliminary duplicate articles removal was done with a citation manager (EndNote X9 Windows; Clarivate) Articles were then filtered by title, abstract, and complete reading, agreeing with the PRISMA Statement, as shown in Figure 1.

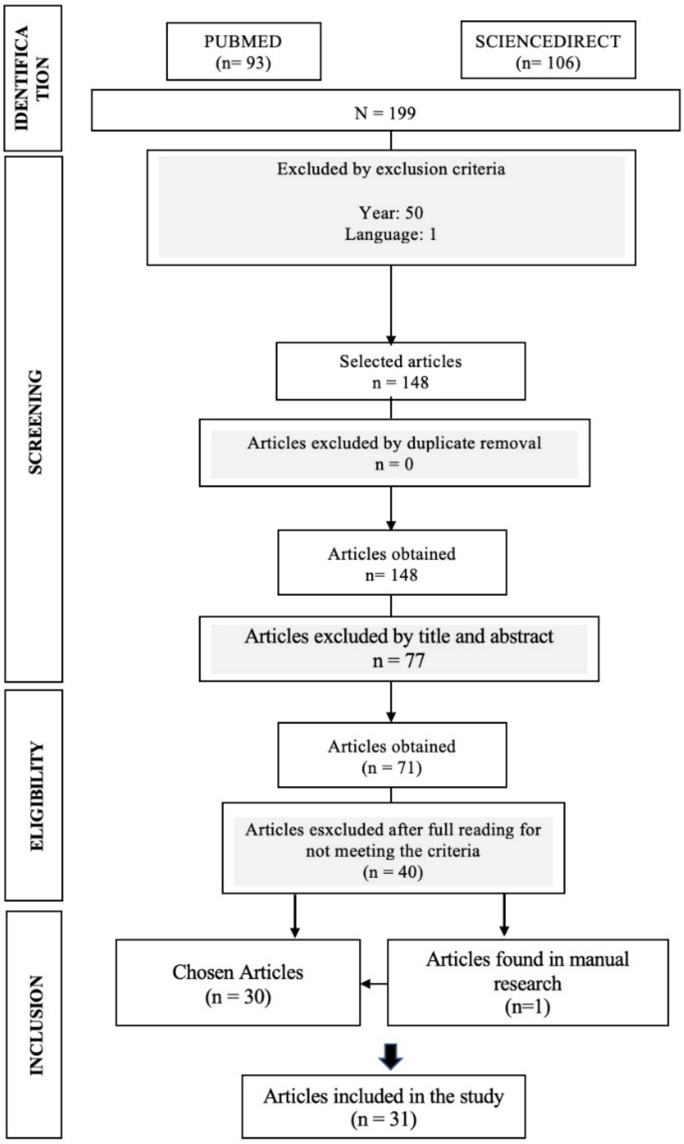


Figure 1 - Flow diagram of study selection according to preferred reporting items for systematic reviews and meta-analysis statement.

Two investigators (M.J.C.L., T.L.V.) independently selected each pertinent article for detailed reading. A third investigator (T.P.) resolved disagreements.

Additional research was conducted manually, pairing each word with the words self-adhesive and universal adhesives to identify relevant literature reviews, systematic reviews related to the subject, or other studies indirectly related to the topic, to allow comparisons or enrich the introduction and discussion sections.

Quality assessment protocol

The selected articles were included in this systematic review and subjected to a quality assessment to determine the risk of bias (BIAS), which was calculated according to the different criteria: blind sampling for the operator, single operator, random distribution of the sample, respect for the manufacturer's instructions, compliance with international standards (ISO), sample size calculation, and statistical analysis quality.

The study’s publication date and the publication's quotation by the date in the SRJ-Score (Q_1-Q_4) were also analyzed.

Qualitative analysis for risk of bias assessment was done by individually scoring the 10 elected parameters within the following criteria: (0) - clearly mentioned, (1) - present but not accurately mentioned, and (2) - not mentioned. Global scoring was categorized as Low Risk (0–4), Medium Risk (5–12), High Risk (13–17), and Very High Risk (18–20) of bias. Data extraction was summarized in tables. Pertinent information was examined in comprehensive graphics after applying the following filters: type of CAD-CAM block tested, luting material, mechanical test used for bonding strength evaluation, type of surface treatment, coupling agent and adhesive system.

Data extraction workflow

Data extraction was performed and condensed into tables. The information considered more pertinent was presented in didactic graphics after applying the filters: type of CAD-CAM blocks tested, variety of mechanical tests performed, luting material used, surface treatment, and coupling agent.

Meta-analysis

A meta-analysis focused on adhesive strategies for each brand of luting cement was conducted using a software program (Stata v17.0; StataCorp, USA). Subgroup analyses were performed to assess the different kinds of surface treatment methods, adhesive joint substrates, and types of mechanical tests, and, for all studies that evaluated more than 1 type of CAD-CAM block or more than 1 surface treatment method, each type of material or treatment method was considered independently.

The statistical heterogeneity was detected using the I^2 statistic test (α=.05). A subgroup was formed with the 19 articles that studied the most tested blocks in at least 2 in vitro studies. A meta-analysis was conducted by the author and CAD-CAM block to find intrastudy heterogeneity and protocol splitting by efficiency after calculating the difference between means and the effect size (α=.05; 95% CI; Z-value 1.96). Funnel and Galbraith plots assessed the publication bias and heterogeneity (random-effects model; α=.01; 99,9% CI; Z-value 2.58).

RESULTS

General aspects

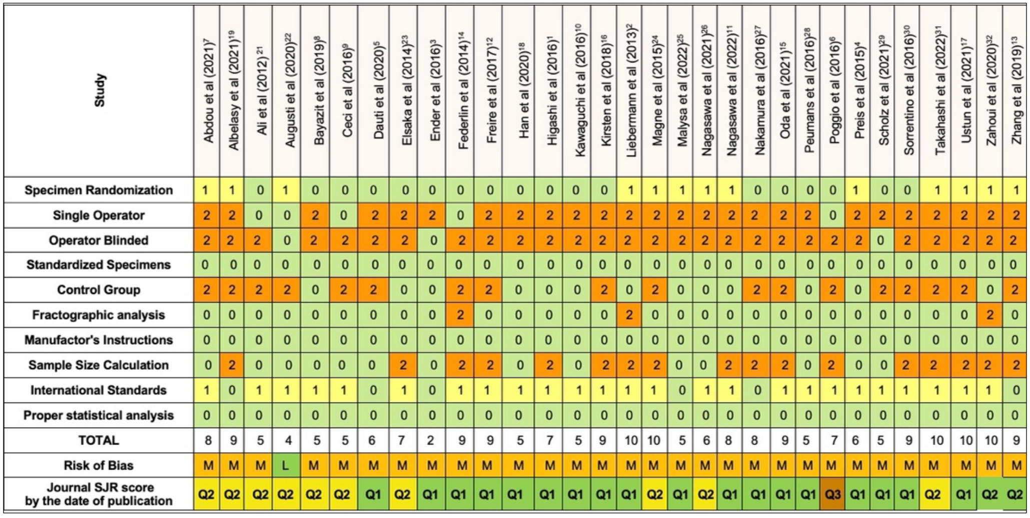
With this methodology, a total of 199 articles were obtained. One article was immediately excluded by language, and there were no duplicate articles. 77 articles were removed by title and abstract reading, 40 by complete reading, and the remaining 31 articles[1-6,8-19,21-32] were selected for quality analysis. The manual research retrieved 2 studies[7,33] used introduction and discussion sessions. The selection process agreed with the PRISMA Statement and is displayed in Figure 2.

BIAS risk assessment

The qualitative analysis for risk of bias assessment (Table 1) revealed 1 low-risk[22] (3.3%) and 30 medium-risk of bias 96.77%) articles. Transversal factors for lower score were the absence of operator blindness (referred to in 3 articles[3,22,29] [9.68%]), and no reference to a single operator (referred to in 5 studies[6,9,14,21,22] [16.13%]).

Specimen randomization and the control group were frequently inadequately described or lacking. The journal ranking found was Q_1 (64.52%), Q_2 (32.26%), and Q_3 (3.22%).

Table 1 - Assessment of risk of BIAS and SJR scoring.



Study	Abdou et al (2021)[7]	Albelasy et al (2021)[19]	Ali et al (2012)[21]	Augusti et al (2020)[22]	Bayazit et al (2019)[8]	Ceci et al (2016)[9]	Dauti et al (2020)[5]	Elsaka et al (2014)[23]	Ender et al (2016)[3]	Federlin et al (2014)[14]	Freire et al (2017)[12]	Han et al (2020)[18]	Higashi et al (2016)[1]	Kawaguchi et al (2016)[10]	Kirsten et al (2018)[16]	Liebermann et al (2013)[2]	Magne et al (2015)[24]	Malysa et al (2022)[25]	Nagasawa et al (2021)[26]	Nagasawa et al (2022)[11]	Nakamura et al (2016)[27]	Oda et al (2021)[15]	Peumans et al (2016)[28]	Poggio et al (2016)[6]	Preis et al (2015)[4]	Scholz et al (2021)[29]	Sorrentino et al (2016)[30]	Takahashi et al (2022)[31]	Ustun et al (2021)[17]	Zahoui et al (2020)[32]	Zhang et al (2019)[13]
Specimen Randomization	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	1	0	0	1	1	1	1
Single Operator	2	2	0	0	2	0	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	2	2	2	2
Operator Blinded	2	2	2	0	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	2	2	2	2	2
Standardized Specimens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Control Group	2	2	2	2	0	2	2	0	0	2	2	0	0	0	2	0	2	0	0	0	2	2	0	2	0	2	2	2	2	0	2
Fractographic analysis	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Manufactor's Instructions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sample Size Calculation	0	2	0	0	0	0	0	2	0	2	2	0	2	0	2	2	2	0	0	2	2	2	0	2	0	0	2	2	2	2	2
International Standards	1	0	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0
Proper statistical analysis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	8	9	5	4	5	5	6	7	2	9	9	5	7	5	9	10	10	5	6	8	8	9	5	7	6	5	9	10	10	10	9
Risk of Bias	M	M	M	L	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Journal SJR score by the date of publication	Q2	Q2	Q2	Q2	Q2	Q2	Q1	Q2	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q2	Q1	Q2	Q1	Q1	Q1	Q1	Q3	Q1	Q1	Q1	Q2	Q1	Q2	Q2

NS – Not Scored Q1 – First Quartile Q2 – Second Quartile Q3 – Third Quartile

Descriptive data

Data extraction recovered the information summarized in Tables 2 to 4. Figures 2 to 7 show data from the filtering by type of CAD-CAM blocks used, cementing resin filtered by CAD-CAM blocks, surface treatment, and coupling agent. Lava Ultimate and Vita Enamic blocks were the most tested CAD-CAM blocks. Rely X Ultimate 2 was the most widely used resin cement, followed by Rely X Unicem, Rely X Ultimate and Rely X U200, and μTBS MPa was the most used test.

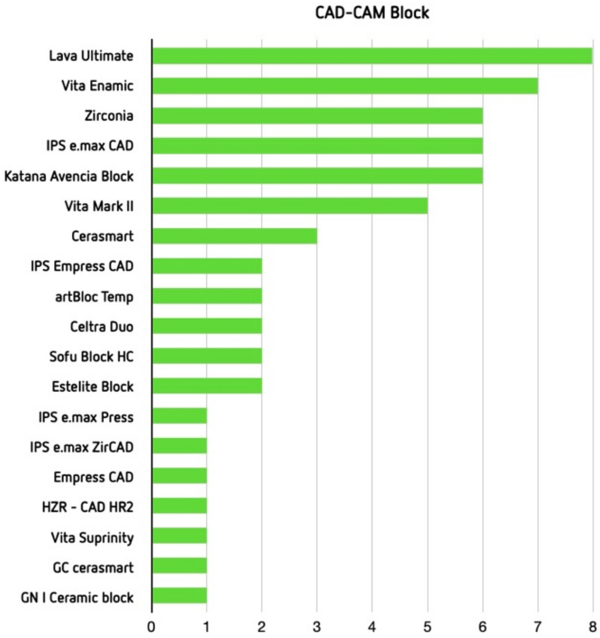


Figure 2 - CAD-CAM blocks found in selected articles.

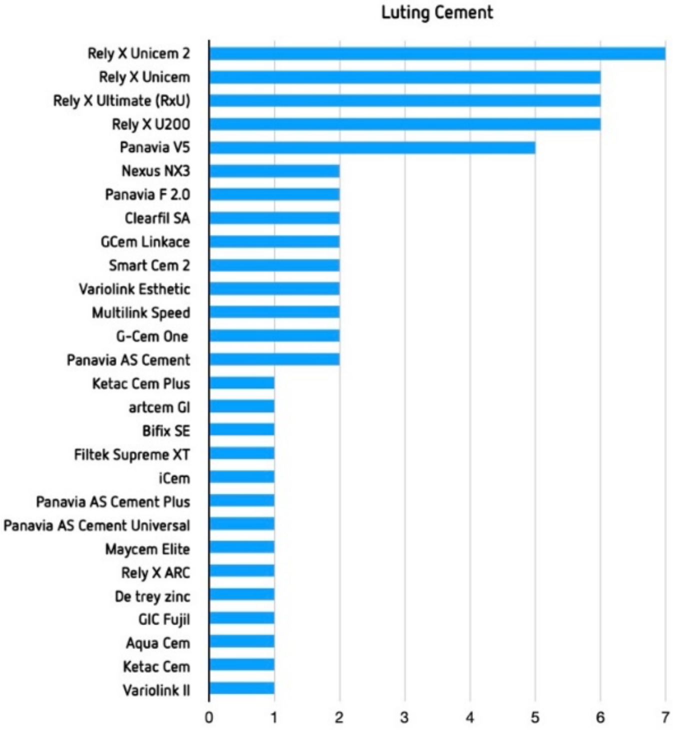


Figure 3 - Resin-matrix luting cement found in selected articles.

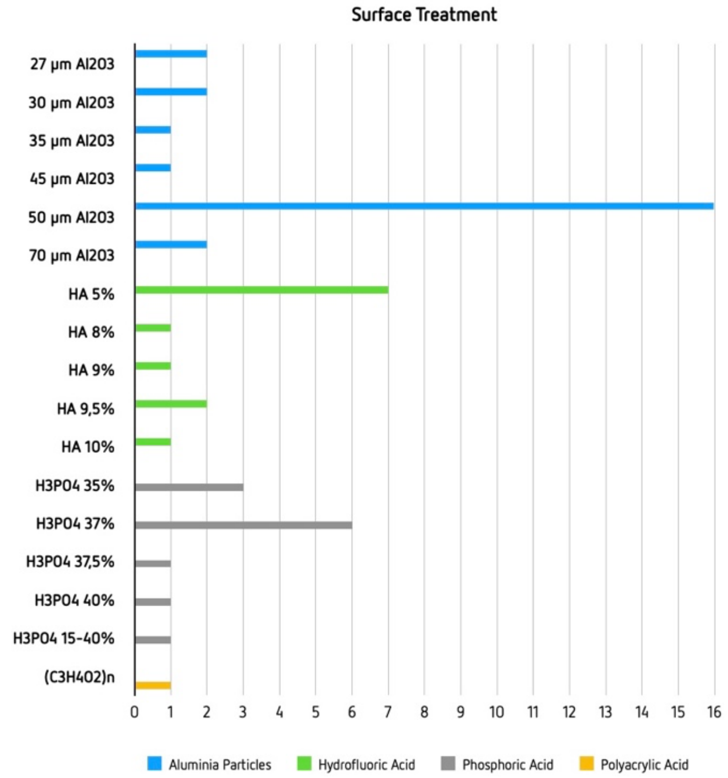


Figure 4 - Surface treatments used in selected articles.

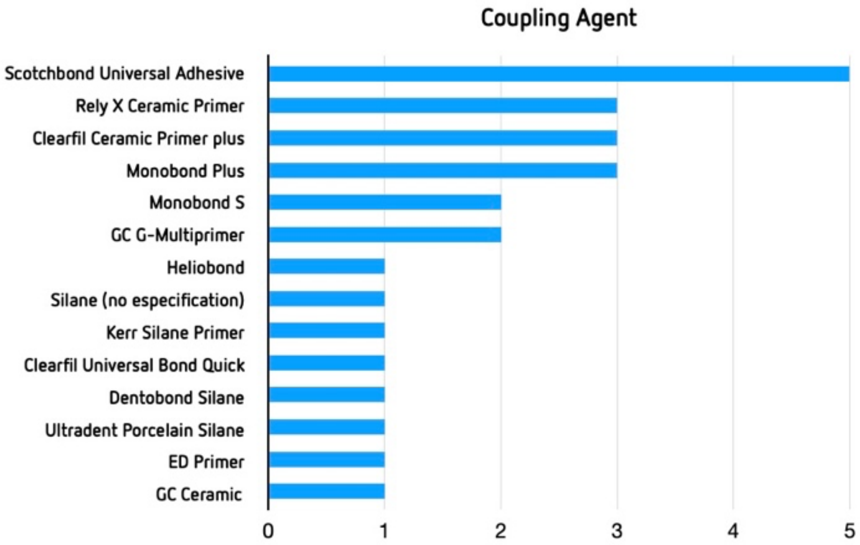


Figure 5 - Coupling agent used in selected articles.

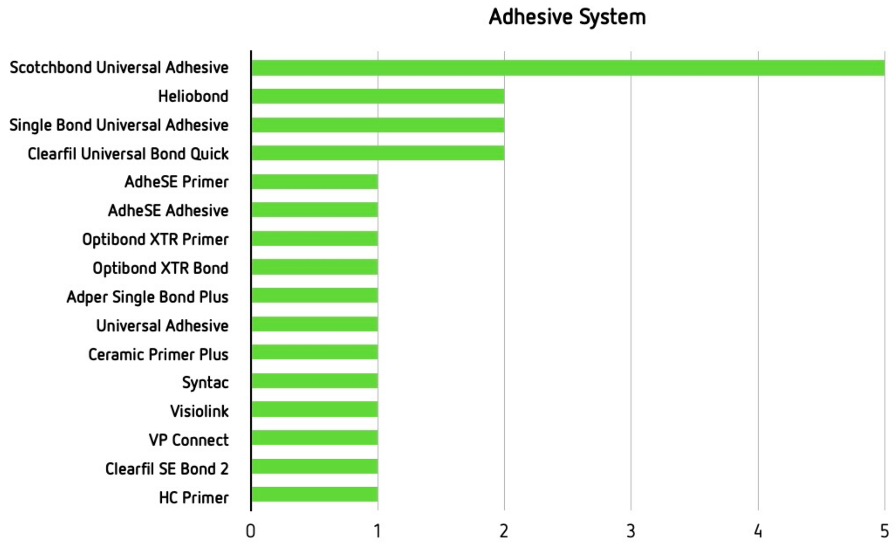


Figure 6 - Adhesive systems used in selected articles.

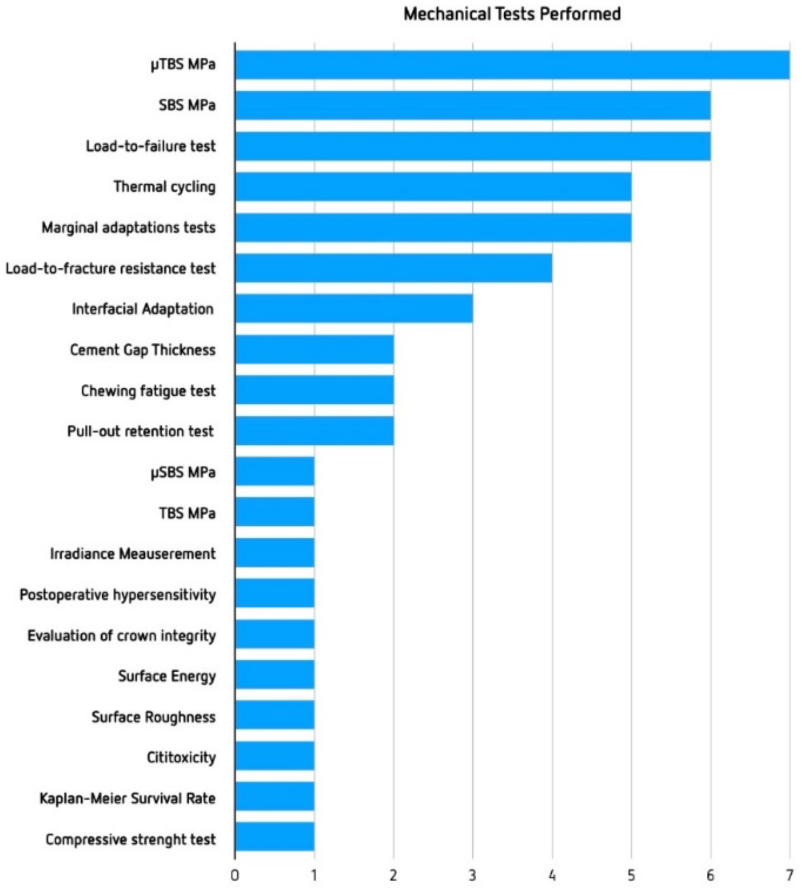


Figure 7 - Mechanical Tests performed in selected articles.

Table 2 - Resumed extraction data from the selected studies.

Author	Material	Surface Treatment	Coupling Agent	Adhesive System	Luting Cement	Sample Pairing	Type of Test
Abdou et al (2021)[7]	Katana Avencia Block	50 µm Al2O3 37,5% PA	Kerr Silane primer Scotchbond universal adhesive Clerarfil Universal Bond Quick	Clerarfil Universal Bond Quick Scotchbond universal adhesive Optibond all-in-one	Panavia V5 (Pv5) Reli X Ultimate (RxU) NX3 Nexus (NX3)	Bovine Incisors (n=60)	**µTBS MPa**
Albelasy et al (2021)[19]	IPS. e max CAD Vita enamic Lava Ultimate	50 µm Al2O3 8% HA 37% PA	Dentobond Silane	N/A	Rely X Unicem	Maxilary Molars (n=84)	ThermoCycling Load-to-fracture resistance test Load-to-failure test
Ali et al (2012)[21]	Zirconia	50 µm Al2O3	N/A	ED primer	Panavia F 2.0 (silane) Rely X Unicem clicker? Clearfil SA Cement (silane)	Human Molars (n=72)	Thermocycling Load-to-failure Test
Augusti et al (2020)[22]	Zirconia	50 µm Al2O3	N/A	N/A	Ketac Cem Plus Rely X Unicem 2 (silane)	Blocks (n=20)	Pull-out retention test
Bayazit et al (2019)[8]	Lava Ultimate Vita Enamic	50 µm Al2O3 9,5% HA	N/A	Single Bond Universal (UA)	Rely X U200 Set PP	Blocks (n=48)	**µTBS MPa**
Ceci et al (2016)[9]	Lava Ultimate	50 µm Al2O3 35% PA Clinpro Prophy powder (glycine) Scotchbond universal etchant	Scotchbond universal adhesive	Scotchbond Universal Adhesive	Rely Xtm Ultimate Rely X Unicem 2	Bovine mandibular incisors (n=30)	**µSBS MPa**
Dauti et al (2020)[5]	Vita Enamic	5% HA Vita Ceramics Etch - 5% (sulfuric acid, hydrofluoric acid, ethanol)	Monobond Plus	AdheSE primer AdheSE Adhesive Optibond XTR OptiBond XTR Primer OptiBond XTR Bond	Rely X Unicem Variolink Esthetic Nexus 3	Crowns (n=50)	Micro CT-scan Marginal adaptation, internal gap (IG), total cement space volume (TCV), and marginal porosities (VP) measurements
Elsaka et al (2014)[23]	Vita Enamic Lava Ultimate	50 µm Al2O3 9,5% HA	Silane Coupling agent	N/A	Bifix SE	Blocks (n=30)	**µTBS MPa**
Ender et al (2016)[3]	Empres CAD artBloc Temp	50 µm Al2O3	Monobond Plus	Heliobond	artcem GI Rely X Unicem Variolink II	Human Molars (n=48)	Marginal adaptation measurements Chewing fatigue test Load-to-fracture resistance test Load-to-failure test
Federlin et al (2014)[14]	Vita Mark II	5% HA 37% PA	Monobond S	N/A	Rely X Unicem (RXU)	Human teeth on mouth (n=68)	USPHS Postoperative hypersensitivities, Anatomic form Marginal adaptation, Marginal discoloration, Surface texture, and recurrent caries.
Freire et al (2017)[12]	IPS. e max CAD IPS. e max Press	10% HA 35% PA	Rely X Ceramic Primer	Adper Single Bond Plus	Rely X ARC Rely X U200	Bovine teeth (n=64)	Marginal Adaptation Scanning Electron Microscopy (SEM)

Table 3 - Resumed extraction data from the selected studies.

Author	Material	Surface Treatment	Coupling Agent	Adhesive System	Luting Cement	Sample Pairing	Type of Test
Han et al (2020)[18]	Lava Ultimate	50 µm Al2O3 Polyacrylic acid	N/A	Universal dentine adhesive Clearfil Universal bond quick Ceramic Primer Plus	Panavia V5 Rely X U200 G-Cem LinkAce SmartCem2 Multilink speed	Human 3rd molars (n=132)	Thermocycling Intefacial adaptation measurement using SS-OCT
Higashi et al (2016)[1]	Katana Avencia Block	50 µm Al2O3	Clearfil Ceramic Primer Plus	N/A	Panavia V5 (Pv5) Panavia SA Cement (PSA)	Blocks (n=24)	**µTBS MPa**
Kawaguchi et al (2016)[10]	Katana Avencia Block	50 µm Al2O3 40% PA K-Etchant gel	Clearfil Ceramic Primer Plus	N/A	Panavia V5 (Pv5) Panavia SA Cement (PSA)	Blocks (n=24)	**µTBS MPa**
Kirsten et al (2018)[16]	Vitablock Mark II	35 µm Al2O3 37% PA 5% HA	N/A	Syntac	iCEM Rely X Unicem 2 (RXU) Variolink Esthetic	Human 3rd molars (n=48)	Evaluation of crown integrity Cement gap thickness
Liebermann et al (2013)[2]	artBlock temp	50 µm Al2O3	N/A	Visiolink VP connect	Clearfill SA Cement Rely X Unicem (RXU)	Pmma specimens (n=240)	**TBS MPa** Surface energy and surface roughness measurements
Magne et al (2015)[24]	Vita Mark II IPS. e max CAD Lava Ultimate	50 µm Al2O3 27 µm Al2O3 5% HA	Rely X Ceramic Primer	N/A	Rely X Unicem 2	Human molars (n=45)	Chewing fatigue test
Malysa et al (2022)[25]	IPS Empress CAD IPS. e max CAD IPS. e max ZirCAD	9% HA 37% PA (H3PO4)	N/A	N/A	Panavia V5 Maxcem Elite Rely X U200 Panavia SA cement universal	Human molars (n=67) Blocks (n=144) ??	**SBS MPa** Load-to-failure test Thermocycling
Nagasawa et al (2021)[26]	Cerasmart Shofu Block HC HZR-CAD HR2 Estelite Block Vita Enamic for Kavo Artica Katana Avencia Block	70 µm Al2O3 15-40% PA 9% HA	GC G-Multiprimer	N/A	G-CEM ONE	Blocks (n=7) ???	**SBS MPa**
Nagasawa et al (2022)[11]	GN I Ceramic Block Cerasmart	70 µm Al2O3	GC G-Multiprimer GC Ceramic Primer II	N/A	G-CEM ONE	Blocks (n=15) ??	**SBS MPa**
Nakamura et al (2016)[27]	Zirconia	N/A	ED primer	N/A	De Trey Zinc Fuji I RelyX Unicem 2 Panavia F2.0	Crowns (n=30)	Compressive strength of cement Micro-CT analysis Load-to-failure test
Oda et al (2021)[15]	Katana Avencia Block	50 µm Al2O3 35% PA	Clearfil Ceramic Primer Plus	Clearfil SE Bond 2	Panavia SA Cement Plus (SAP) Panavia AS Cement Universal (SAU)	Blocks (n=45)	**µTBS MPa** Irradiance measurements Load to failure test
Peumans et al (2016)[28]	Celtra Duo IPS. e max CAD IPS Empress CAD Vita Enamic Vita Mark II Lava Ultimate	27 µm Al2O3 30 µm Al2O3 < 5% HA 600-grit Sic Paper Cojet – SiO22 - coated	Monobond Plus Heliobond	N/A	Clearfil Esthetic cement Panavia SA cement	Block to block (n=5)	**µTBS MPa**

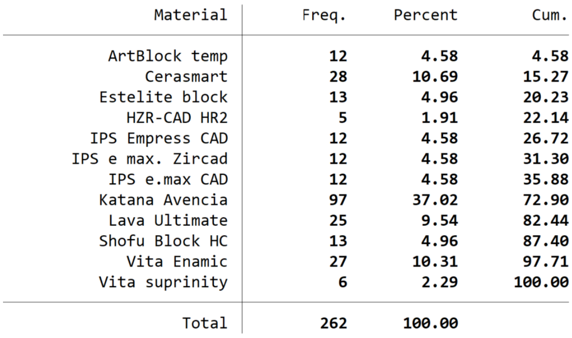
Table 4 - Resumed extraction data from the selected studies.

Author	Material	Surface Treatment	Coupling Agent	Adhesive System	Luting Cement	Sample Pairing	Type of Test
Poggio et al (2016)[6]	Lava Ultimate (3M)	Scotchbond Universal Etchant (35% PA)	Scotchbond Universal Adhesive	Scotchbond Universal Adhesive	Rely X Ultimate Rely X Unicem 2	Bovine lower incisors (n=30)	**SBS MPa**
Preis et al (2015)[4]	Celtra Duo IPS. e max CAD	5% HA	Monobond S	Heliobond	Smart Cem 2 Aqua Cem Ketac Cem Variolink II	Human Molars (n=40)	Thermal cycling Load to fracture resistance test (SEM) electron microscopy
Scholz et al (2021)[29]	Vita Mark II	5% HA 37% PA (H3PO4)	Scotchbond Universal Adhesive Rely X Ceramic Primer	Scotchbond Universal Adhesive	Rely X Ultimate Rely X Unicem 2	50 pacients Crowns (n=150)	Kaplan Meien Survival Rate
Sorrentino et al (2016)[30]	Zirconia	50 µm Al2O3	N/A	N/A	G-Cem LinkAce	Blocks (n=40) Human Molars (n=40)	Load to fracture resistance test
Ustun et al (2021)[17]	Vita Suprinity Vita Enamic GC CeraSmart	5% HA 37% PA	Ultradent Porcelain Silane	Single Bond Universal Adhesive	Rely X Ultimate Rely X U200	Human Molars (n=63)	**µSBS MPa**
Takahashi et al (2022)[31]	Estelite P Blocks Katana Avencia P Block Shofu Black HC Super Hard	50 µm Al2O3	N/A	HC Primer	Panavia SA Cement Universal (silane) Block HC Cem	Blocks (n=30)	**SBS MPa** (SEM)
Zahoui et al (2020)[32]	Zirconia	30 µm Al2O3 45 µm Al2O3	Scotchbond Universal Adhesive	Scotchbond Universal Adhesive	Rely X U200 Rely X Ultimate	Crowns (n=160)	**Pull-out retention test**
Zhang et al (2019)[13]	Zirconia	50 µm Al2O3	N/A	N/A	Multilink Speed	Zirconia Specimens (n=120)	**Citotoxicity**

Meta-analysis

From the initial 19 articles selected for quantitative analysis 10 were subgrouped to evaluate the mechanical performance[1,2,7-10,17,23,25,31] and 6[3-6,15,30] the marginal adaptation. After a detailed analysis 3 articles[11,26,28] were rejected for meta-analisys as the displayed results did not alowed statistical analisys. The Table 5, shows the blocks tested in the articles evaluated for mechanical performance, and relative number of tests avalilable.

Table 5 - CAD-CAM blocks present in the articles for quantitative analysis of mechanical evaluation.



```
           Material |      Freq.     Percent        Cum.
--------------------+-----------------------------------
      ArtBlock temp |         12        4.58        4.58
          Cerasmart |         28       10.69       15.27
     Estelite block |         13        4.96       20.23
        HZR-CAD HR2 |          5        1.91       22.14
     IPS Empress CAD |         12        4.58       26.72
   IPS e max. Zircad |         12        4.58       31.30
       IPS e.max CAD |         12        4.58       35.88
     Katana Avencia |         97       37.02       72.90
      Lava Ultimate |         25        9.54       82.44
      Shofu Block HC |         13        4.96       87.40
        Vita Enamic |         27       10.31       97.71
     Vita suprinity |          6        2.29      100.00
--------------------+-----------------------------------
              Total |        262      100.00
```

The meta-analysis combining the selected 16 articles based on the difference between means and the effect size (P=.05; 95% CI; Z-value 1.9599) for mechanical performance is represented in Figure 8. Assessment of publication bias and heterogeneity for this subgroup articles is shown in Figures 9 and 10. The funnel plot asymmetry suggests an overestimation of the intervention effect, probably induced by the disparity between samples, with some possible bias. The Galbraith plot suggests some heterogeneity among the effect size as dispite the majority of the studies are within the 95% CI region, several are outside. All studies had high precision (toward the right on the X axis). Globally the studies were above the green line with the red line sloping upward, suggesting favorable tested protocols compared with the control protocol. The biplot graph in Figure 11 displays the means and SD of some tested material-luting cement pairs, and revels an heterogenous mechanical performance among the tested protocols. The graph suggets a similar behaviour for the majority of the pairs, but also that there some performence disparity.

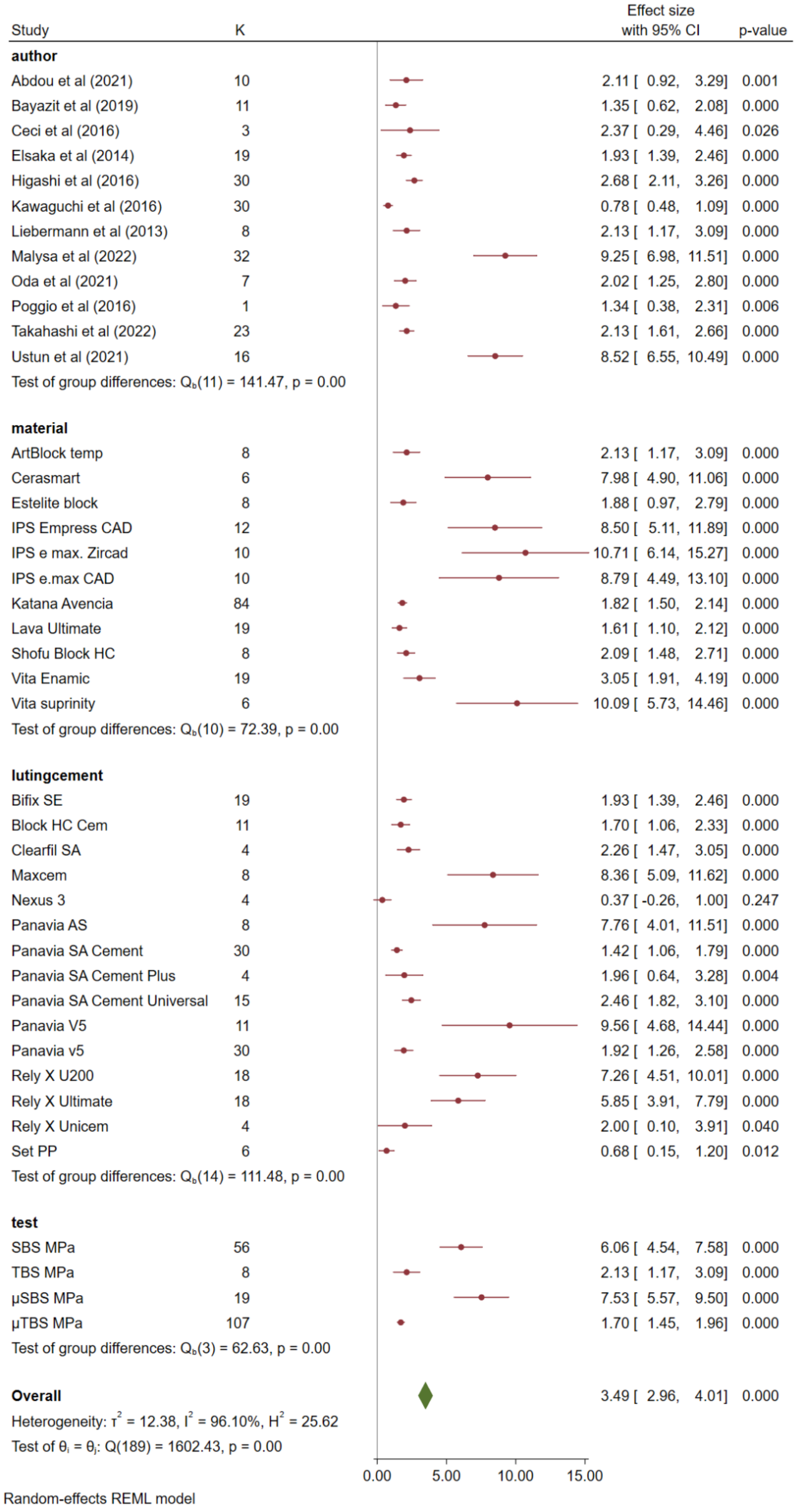


Figure 8 - Forest plot summarizing effect size by author, CAD-CAM block, luting cement and mechanical test.

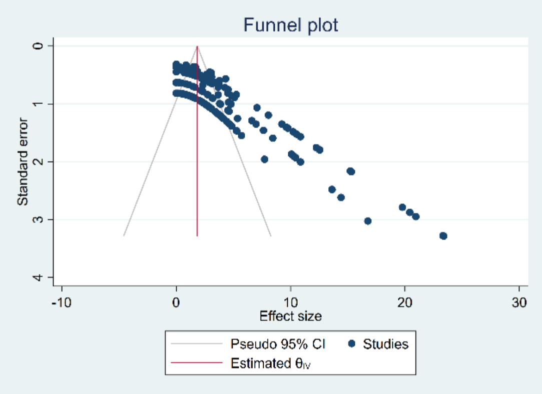


Figure 9 - Funnel plots of publication bias of all selected publications and filtered by joint substrate and mechanical test.

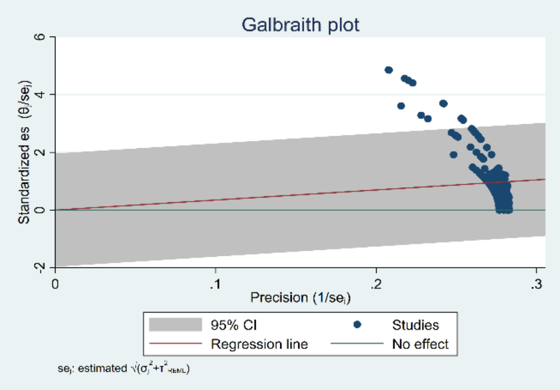


Figure 10 - Heterogeneity assessment among effect sizes.

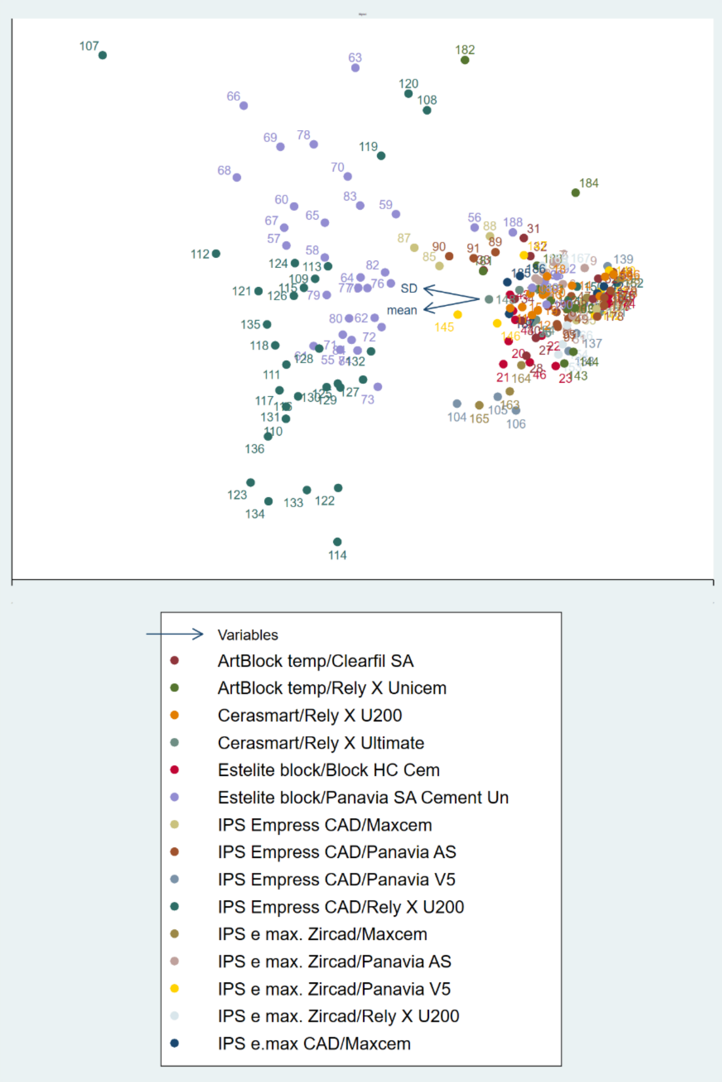


Figure 11 - Biplot graph by mean and standard deviation (SD).

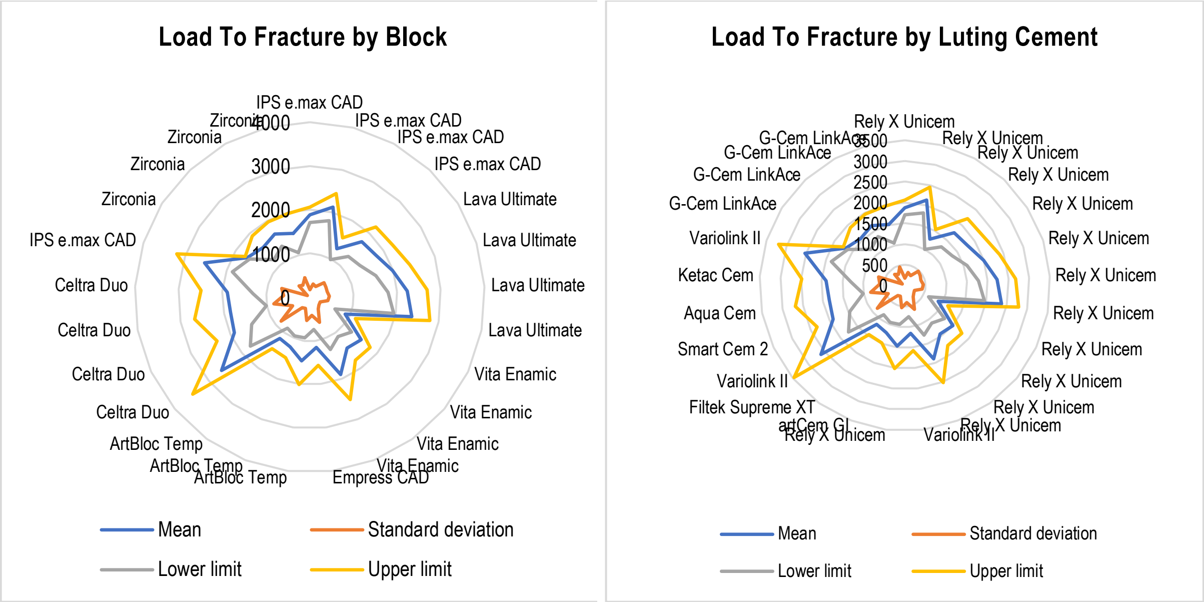


Figure 12 - Radar graphs with load to fracture by CAD-CAM block and Luting cement.

From the observation of Figure 12, we can infer that the Variolink II cement gives resistance to the Celtra DUO blocks and to the IPS emax CAD. The latter is also resistant when cemented with Rely X Unicem, a cement that has proved to have a good and more universal performance.

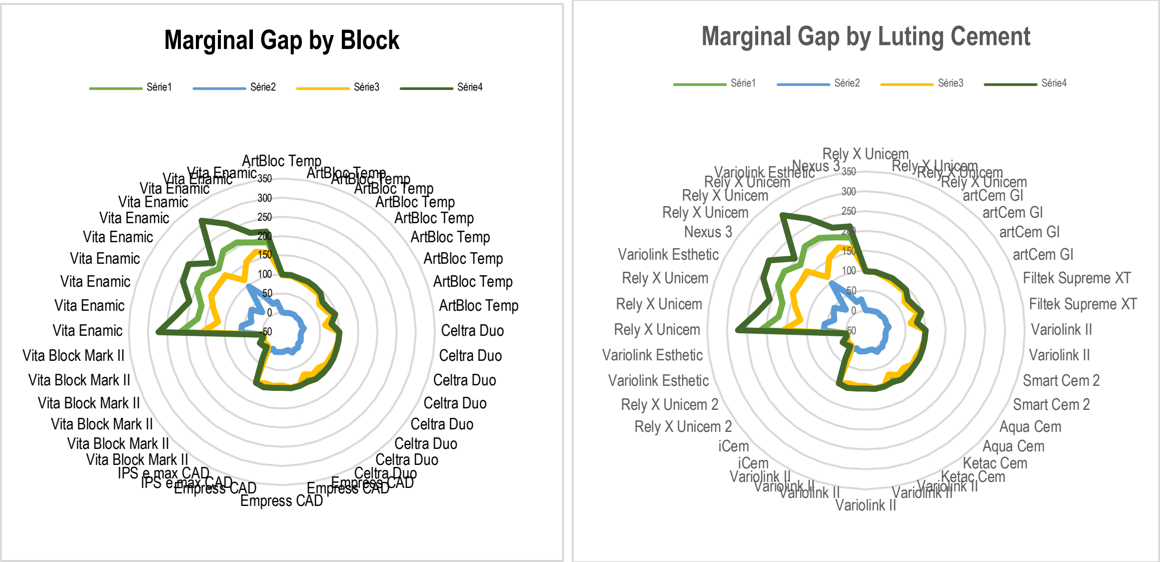


Figure 13 - Radar graphs with marginal gap by CAD-CAM block and Luting cement.

From the observation of Figure 13, it is noteworthy that marginal gap is more concerning with the Vita Enamic block whatever cement is used.

DISCUSSION

This systematic review assessed whether self-adhesive resin-matrix composite cements (SARCs) are adequate for the luting cementation of CAD-CAM blocks, and which is the best protocol for each block. Based on the found studies it is not possible to establish which is the luting cement that suits a particular CAD-CAM block, or if there is a better SARCs adequate for all situations. Several articles using self-adhesive resin cements were identified. SARCs showed different mechanical performances depending on which materials were tested, on how the surface was treated, and which luting cement was used. Thus, there are many criteria that needs to be considered for the luting success of CAD-CAM blocks.

Although the process of adhesive cementation with SARCs is less technique-sensitive and time-consuming than with conventional ones, because it bonds to an unconditioned tooth surface (the smear layer) without the need for pre-treatment with an acid or adhesive, allowing placement of the restoration in a single step, several strategies have been found to treat the substrates surface before applying the self-adhesive resin cement, aiming to improve the bond strength.

In the selected studies the the most frequently used treatment was air-blasting with 50 μm aluminium oxide particles (Al_2O_3)(sandblasting). A study reported that surface treatment is the most important factor affecting the μTBS of resin cement to CAD-CAM materials, followed by the type of resin-matrix ceramic and the type of resin cement, respectively.[8] According to Bayazit et al[8], sandblasting pre-treatment is preferred for CAD-CAM hybrid ceramics with a high content of ceramics like Vita Enamic, while hydrofluoric acid (HF) pre-treatment is recommended for CAD-CAM resin nanoceramic reinforced with nanoparticles, like Lava Ultimate. Nevertheless Elsaka et al[23] found that in hybrid ceramics such as Vita Enamic luted with a SARC, surface treatment with HF and a silane coupling agent showed higher bond strength values compared with sandblasting and HF surface treatments, as Vita Enamic and Bifix (SARC) appear to be more hydrolytically stable and durable than the Lava Ultimate (nanoceramic resin) and Bifix (SARC) system. Higashi et al[1] also observed longer maintenance of bond strength when CAD-CAM resin block surfaces were pre-treated with a combination of both sandblasting and silanization.

According to Nagasawa et al[11,26] priming or sandblasting the CAD-CAM composite and ceramic blocks significantly increases the bond strength of SARCs compared to controls. Also, the combination of priming and CAD-CAM composite and ceramic blocks sandblasting was effective to increase the bond strength of the SARC. The author adds that the bond strengths obtained by 9% HF etching with priming were comparable to those by sandblasting with priming.[26] Other surface treatments were investigated in different studies, such as polyacrylic acid, with no significant difference in interfacial adaptation of resin nanoceramic inlays.[18] Additionally, surface treatment with plasma of Organic Modified Polymer infiltrated Network (OMP-N) (PMMA) did not increase the adhesion to SARCs; it increased the surface energy with no impact on surface roughness and a negative impact on the bonding with dental resin-matrix materials.[2] Also, pre-treatment with glycine did not significantly change the bond strength in the various luting protocols tested. However the use of glycine seems to increase the bond strength of self-adhesive resin cements, but it needs further investigation.[9] The results obtained for both ultrasonic and acid cleaning after sandblasting suggest that as long as the restorations are sandblasted after the try-in procedure in a clinical setting, there is no need for ultrasonic and acid cleaning after sandblasting with regard to improving the micro-tensile bond strength.[10] In a prospective randomized clinical trial testing the selective enamel etching in the cementation of partial ceramic crowns (PCCs) with SARC, Federlin et al[14] concluded that selective enamel etching combined with the use of a SARC, has the potential to improve PCCs survival rates in difficult clinical situations. A study by Peumans et al[28] discovered disparities in optimal surface treatment and resin cement selection for Vita Enamic and Lava Ultimate resin-matrix ceramic blocks. The most influential parameter for Lava Ultimate (resinous matrix composite densely packed with silica and zirconia particles), was mechanical pretreatment; however, hydrofluoric acid (HF) acid etching had a significant positive effect on bond strength. In terms of resin cement, the self-adhesive material outperformed the conventional resin cement in terms of bond strength to Lava Ultimate. Today, Lava Ultimate is still indicated for inlays, onlays, and veneers; however, the crown indication has been removed by the manufacturer since June 2015 due to higher rates of premature debonding.

Surface treatment, on the other hand, had little effect when bonding to Vita Enamic, which is essentially a ceramic structure infiltrated with resin. The manufacturer recommended that the best surface treatments be silane application alone or HF followed by silane. However, within the same surface treatment group, the self-adhesive resin cement demonstrated lower overall bond strengths than the conventional resin cement. This variance of results can be explained using different methodologies and materials. Even though some results are contradictory, most studies recommend both HF and SN surface treatments.[23]

Since SARCs react only superficially with mineralized tissues, this self-adhesive resin cements do not form a sufficient dentin hybrid layer or resin tags.[15] Resin coating may be suggested, for it creates a layer with a low modulus of elasticity that acts as a stress breaker or shock absorber, resulting in higher bond strengths with the resin-coated groups, strengthening the dentin interface, thus leading to a better adhesive performance, regardless of the resin cement and its curing mode.[7,15] A study also showed that dual curing mode resulted in higher bond strength than the self-curing mode. The relatively slow curing process in the self-curing mode allows the water to be absorbed from the dentinal tubules by osmosis. Thus, the resin coating played a role in suppressing the penetration of water through the adhesive layer, especially in the self-curing mode.[15] In addition, single-visit treatment results in higher bond strength of resin cement to dentin and CAD-CAM blocks than a multiple-visit treatment resin coating.[7,15]

In general, a self-adhesive resin cement is inherently a self-etching material in the initial stages of its chemical reaction. Its low pH and high hydrophilicity in the early stages after mixing result in good wetting of the tooth structure and promote demineralization of the surface, like self-etching adhesives. As the reaction progresses, the acidity of the cement is gradually neutralized due to its reaction with the apatite of the tooth substrates and with the metal oxides contained in the basic, acid-soluble inorganic fillers. As the hydrophilic and acidic monomers are consumed by the chemical reactions in situ, the cement simultaneously becomes more hydrophobic, which is highly desirable in a fully set resin cement to minimize water sorption, hygroscopic expansion and hydrolytic degradation. Self-adhesive resin cements with a lower pH neutralizing capacity showed higher residual hydrophilicity and higher hygroscopic expansion. Water sorption and significant hygroscopic expansion stresses can result from residual hydrophilicity during and after the setting reaction. Thus, when a self-adhesive resin cement is the preferred clinical option, cements with strong neutralization reactions are recommended, resulting in low hygroscopic expansion stresses.[33] A study by Kirstens et al[16] attributed crack formation to hygroscopic expansion stress of the build-up and luting material, being possible that the use of distilled water increased the rate of water uptake, resulting in higher hygroscopic expansion stresses.

The incorporation of acidic monomers with hydrogen bonding sites, such as hydroxyl, phosphate, or carboxyl groups, contributes to the natural hydrophilicity of SACRs in comparison to conventional resin cements. The author concluded that the SARCs with poor pH neutralization and high hygroscopic expansion stress could cause the fracture of feldspathic ceramic crowns. By pre-damaging the cervical margins, CAD-CAM processing sets the stage for such a phenomenon. Overall, it is critical to optimize the physical-chemical properties of SARCs in order to reduce the materials' hygroscopic expansion stress in order to avoid or at least mitigate the observed adverse effects. For clinical use in conjunction with CAD-CAM crowns, SARCs with increased pH neutralization behavior and low hygroscopic expansion stress should be preferred. A study based on CAD-CAM technology, aimed to examine the effects of several luting techniques (total-etch, self-etch, and self-adhesive) on the shear bond strength values between dentin and cutting-edge RNC material. In comparison to self-adhesive resin cements, conventional resin cements (combined with etch and rinse or self-etch adhesives) displayed higher shear strength values. The employment of extra adhesives for conditioning is therefore required for the polymeric CAD-CAM materials that have been put through testing. Furthermore, the maximum adhesion values were obtained when conventional resin cements and a self-etch adhesive were used.[6]

By investigating the fatigue resistance of ultrathin CAD-CAM crowns with SARC Rely X Unicem 2, Magne et al[24] found that it is possible to use resin nanoceramics (RNC) and lithium disilicate (LDS), cemented with Rely X Unicem 2, to restore posterior teeth with regular or ultrathin crowns, even with relatively high loading requirements. However, for ultrathin crowns withcfeldspathic ceramic (FEL) veneers, SARCs should not be used and immediate dentin sealing (IDS) technique should be used with preheated composite resin as a luting agent. All failures could be restored and standard size crowns of 1.5 to 2.0 mm preparation on the occlusal surface had higher survival rates than ultra-thin crowns.

According to Ender et al[3], by evaluating the performance of large MOD cavities filled with PMMA-based CAD-CAM inlays, the respective inlays luted with a self-adhesive resin cement may be applicable as long-term restorations in narrow cavities based on the findings of marginal adaption, fracture load, and fracture analysis. Compared to a conventional resin cement applied using adhesive, Freire et al[12] concluded that milled ceramic restorations cemented with self-adhesive resin cement had a thinner cement line and the highest interface quality correlated with a thin cement interface.

Another study where the goal was to determine how two different cement space settings and three different resin luting materials affected the marginal and internal fit of polymer-infiltrated ceramic network (PICN) crowns, it was concluded that the marginal and internal fit were not significantly affected by different virtual spacer settings of 50 µand 80 µ. Furthermore, when PICN material crowns were cemented using three different resin-based materials, no significant influence was discovered in the marginal and internal fit.[5]

In all investigations, porosities in the cement space on the periphery with contact to the outside environment were found. This information is crucial from a clinical standpoint because unprotected dentin can be contaminated through these holes by fluids, bacteria, and bacterial toxins, which could jeopardize the efficacy of the restoration. Although porosities in the marginal area were present in all five groups, Rely X Unicem considerably reduced porosities as compared to Nexus 3.[5] According to a study's findings, aiming to evaluate the effect of restoration thickness, the CAD-CAM material, and a 6 months storage in artificial saliva on the fracture resistance of occlusal veneers, for patients with extensive tooth wear, glass-ceramic, polymer-infiltrated ceramics (PICN), and CAD-CAM resin-matrix composite (RC) occlusal veneers with a thickness of 1.0 mm might were referred as conservative options for restoring vertical dimensions. In terms of desirable fracture patterns and the ability for intraoral repair, polymeric materials present an alternative to all-ceramic restorations.[19]

A study with the purpose of testing the bonding ability of resin cements to different CAD-CAM composite blocks assessed the capacity of the dual-cured resin cement using the primer (HC) and the silane-containing self-adhesive resin cement (SA) to attach to CAD-CAM composite blocks. For groups that were stored for 15 minutes and 24 hours, HC significantly increased the bond strengths compared to SA for the same time period. These findings showed that the silane coupling agent was successfully included into SA to connect to the CAD-CAM composite blocks as described in prior studies. Such findings suggest that the silane coupling agent had been successfully added to the hydrophobic SA paste, simplifying the adhesive bonding process by eliminating the need for separate silanization.

Grinding the surface of the artificial tooth and wetting it with MMA monomer is generally accepted as a prerequisite for optimal bond strength in MMA/PMMA denture base materials. Furthermore, it has been reported that for optimal bonding performance, the CAD-CAM composite block surface should be pretreated with a resin primer containing MMA. Also, the presence of MMA groups in the primer's composition may have contributed to a reduction in stress concentration at the interface between the composite block and the resin cements. The silane coupling agent found in SA may be effective for chemical bonding with Katana Avencia Block. The effect of the silane coupling material contained in SA was limited, and this tendency was similar in Shofu Block HC Super Hard. It was concluded that the bonding performance of resin luting cements to CAD-CAM composite blocks was, material and storage period, dependent. To improve the durability and stability of CAD-CAM composite block restorations in clinical situations, the appropriate material combination should be considered.[31]

A study was conducted to see how thermocycling affected the shear bond strength of self-adhesive, self-etching resin cements luted to human dentin and CAD-CAM ceramics. It was found that combining ceramics and cements has a direct impact on bond strength. After accelerated thermal aging, conventional resin cement (Panavia V5) demonstrated significantly higher bonding strengths than self-adhesive, self-etching cements. Because differences in bond strengths for the studied combinations were significant, choosing the right cement for ceramics is critical. The greatest decreases in bond strength were observed for self-etching, self-adhesive cements when comparing samples that had not been thermocycled to those that had been artificially aged.[25]

A study with the goal to find the effect of different cement systems and aging on the bond strength of CAD-CAM ceramics found that the shear bond strength of chairside CAD-CAM materials was significantly affected by different cement systems and thermal aging.

Poggio et al[6] evaluated the bond strength between nanoceramic material and dentin using various adhesive systems and reported that the highest bond strength was found in SE cemented ceramics, which is consistent with the current study's findings. The addition of silane to the surfaces of the resin matrix ceramics used in this study increased the shear bond strength.

Self-adhesive resin cements might be preferable for Vita Suprinity (VS) ceramic restorations, even tough self-adhesive systems contain a lot of water and are prone to hydrolysis and chemical degradation over time. For Vita Suprinity ceramic restorations, both total etch or self-adhesive systems may be recommended. Furthermore, when performing a Vita Suprinity ceramic restoration in deep cavities and postoperative sensitivity is high, the use of self-adhesive systems rather than total etch systems is appropriate, and it is possible to recommend cementing VE and GC ceramic restorations with SE systems. Regardless of the cementation system, the thermal aging process significantly reduced the bond strength values of all ceramic materials.[17]

As for partial ceramic crowns, two studies were included[14,29]. The clinical performance of partial ceramic crowns (PCCs) luted with self-adhesive resin cement had a statistically significant lower survival rate after 39 months compared to restorations luted with conventional resin cement combined with a universal adhesive with or without selective enamel etching, according to Scholz et al[29]. SARCs are not currently recommended for luting partial ceramic crowns. However, regardless of whether a selective enamel etching step was used, the standard adhesive luting procedure, which included a universal adhesive and luting resin-matrix composite, produced good clinical results for more than 3 years.

Additionally, in a prospective, randomized clinical trial, a self-adhesive resin luting cement, RelyX Unicem (RXU), was evaluated for luting PCCs with and without selective enamel etching. Although Rely X Unicem + Enamel etching has slightly better clinical survival at 3 years, restorations in both groups perform similarly in terms of clinical changes over time, showing that when a self-adhesive luting agent is used for luting PCCs, marginal adaptation and marginal discoloration are subject to significant changes, indicating increasing marginal deterioration over time, regardless of the luting strategy used, RXU or RXU + E. Moreover, selective enamel etching combined with the use of the self-adhesive resin luting cement, RelyX Unicem, is a treatment option that has the potential to improve PCCs survival rates in difficult clinical situations.[14]

Systematic reviews evaluating adhesion to zirconia have shown that the use of MDP-based self-adhesive cements gave more favorable results after physicochemical conditioning of the zirconia surface. Although water storage may affect the bond strength of resin cements to zirconia, no difference was found between cements for the aged data set, which may confirm that cement choice is less important for zirconia bond durability.[33] The results of Sorrentino et al[30] and Nakamura et al[27] suggest the possibility of reducing crown thickness in the fabrication of monolithic Zirconia crowns to a lower limit of 0.5 mm while maintaining sufficient strength to withstand occlusal loads, thereby reducing the invasiveness of the preparation and saving a valuable amount of tooth tissue, regardless of the cement types. Furthermore, as explained by Ali et al[21], using zirconia copings cemented on teeth with the adequate retention and resistance designs recommended in the literature or on teeth without these designs, zirconia coping retention was higher on teeth with suitable resistance and retention than it was on teeth without the adequate design and the use of a dentin bonding technique and resin-matrix composite cement did not resulted in improved retention.

Additionally, particularly with high-strength ceramics, such as those investigated in Preis et al[4] study, aging and deterioration often occur without visible catastrophic failures. Zirconia-reinforced lithium silate (ZLS) ceramics, a new class of ceramics with 10% zirconia dissolved in a glass matrix, resulting in lithium silicate crystals that are four times smaller such as the Celtra Duo exhibit high flexural strength and, at the same time, high translucency. Strong fracture forces, high resistance to aging, and good to adequate marginal adaptability were all displayed, concluding that no limitations should be anticipated for clinical use because ZLS crowns are comparable to lithium disilicate (LDS) ceramics that have been demonstrated in clinical settings. For the cementation of molar ZLS crowns, glass-ionomer cements, resin, and resin-modified self-adhesive luting materials appear to be suitable. Malysa et al,[25] in a study conducted to determine how thermocycling affected the SBS of SARCs, IPS e.max ZirCAD had the lowest bond strength among the tested ceramics, regardless of the tested cement.

As for the excess cement at the marginal adaptation, according to Augusti et al[22], despite the cleaning process, cement remnants were discovered in all specimens. Similar quantities of undetected cement remnants were found around the esthetic margins of zirconia crown copings regardless of the type of cement. Cleaning procedures with clinically accessible instruments did not allow complete removal of excess cement.

Luting procedures using a dual-curing, self-adhesive resin cement provided significantly higher early retention values than an resin-modified glass-ionomer (RMGI) material, also advocating that the bond strength experiments have shown that resin-based materials adhere poorly to high-density zirconia without any mechanical or chemical preparation. In a pursuit to establish the most effective cementation protocol for bonding zirconia crowns to Ti-base CAD-CAM abutments in terms of abutment height, cement type and surface treatment, Zahoui et al[32] found that conventional resin cements associated with self-etch adhesive displayed higher retention than self-adhesive cements and that high abutments presented higher retention pressures than short ones. In a hierarchical manner, the results showed a direct correlation between Ti-based height, micro mechanical and/or chemical pre-treatment, Ti-base surface blasting and zirconia, and that tribochemical silica coating (SB + TBS) increased the retention of zirconia crowns, followed by Ti-Base surface blasting (SB) or tribochemical silica coating (TBS), respectively.

Additionally, in relation to the in vitro cytotoxicity of self-adhesive dual-cured resin cement polymerized under three distinct zirconia cusp inclinations with varying light curing times, zirconia was deposited on top of a SARC (Multilink Speed) with cusp inclinations varying from 0° to 20° and 30°, concluding that SADRC's in vitro cytotoxicity is influenced by the zirconia's cusp inclination. Zhang et al[13] reported that regardless of whether the light curing duration is 20 s or 40 s, the cytotoxicity of SADRC for a zirconia restoration with a thickness of 1.0 mm conforms to ISO standard when the cusp inclination is less than 20 while the cytotoxicity of polymerized. SADRC did not meet ISO standards when the cusp inclination of zirconia reached or exceeded 30°. Also, SADRC's in vitro cytotoxicity can be decreased by extending the light curing period.

CONCLUSIONS

Based on this systematic review, it can be concluded that:

- Self-adhesives perform well in mechanical tests. However, they differ and therefore do not necessarily produce similar results.
- Surface treatment affects adhesion between the CAD-CAM block and other joint substrates.
- Surface treatment should be applied to the adhesive surface of the CAD-CAM block prior to cementation, regardless of the type of the self-adhesive resin cement.
- The type of surface treatment affects more the bond strength of resin cement to the CAD-CAM block than do the type of material used.
- The most tested surface treatment was Al_2O_3 air abrasion.
- The effect of surface treatments on the bond strength of novel CAD-CAM restorative materials to resin cement is material dependent:
- Treatment with HF and silane showed excellent results on the surface treatment of glass-ceramic blocks CAD-CAM.
- The plasma treatment has no effect on surface roughness.
- Pretreatment with sandblasting is preferred for CAD-CAM hybrid ceramics with a high ceramic content, and the hydrofluoric acid is recommended for CAD-CAM resin nanoceramics reinforced with nanoparticles.
- The combination of sandblasting and silanization on CAD-CAM stabilizes the bond strength over the time.
- The application of priming and sandblasting to the CAD-CAM composite and ceramic increases the bond strength of the SARC.
- Universal adhesives containing MDP significantly reduce failure rates.
- Silanization improves the adhesion of the block material to other joint substrates significantly. All types of ceramics, surface treatment, or light curing improve adhesion more than a self-adhesive resin cement alone.
- Immediate dentin sealing improved resin cement bond strength to dentin and CAD-CAM block - Single-visit treatment yielded higher bond strength of resin cement to dentin and CAD-CAM than multiple-visit treatment.
- For clinical use in conjunction with CAD-CAM blocks, SARCs with increased pH neutralization behavior and low hygroscopic expansion stress should be preferred.

- Reduced thickness of the cement line is correlated with a better interface quality.
- A dual-curing, self-adhesive resin cement luting procedure provides significantly higher early retention values than an RMGI material.
- Regardless of the cementation system, the thermal aging process significantly reduced the bond strength values of all ceramic materials.
- The occlusal thickness of CAD-CAM monolithic zirconia crowns can be reduced to 0.5 mm while maintaining adequate strength to withstand occlusal load;
- Both glass-ionomer cements, resin, and resin-modified self-adhesive luting materials appear to be suitable for cementation of molar ZLS crowns, with cement choice being less important for zirconia bond durability.
- Light curing is recommended for dual-cured self-adhesive resin cements to achieve predictable bonding performance.
- Extending the light curing time reduces the in vitro cytotoxicity of SADRCs.
- The bonding performance of self-adhesive resin luting cements to CAD/CAM blocks depends on the material and storage period. To improve the durability and stability of CAD/CAM block restorations in clinical situations, the appropriate material combination should be considered.
- Because differences in bond strengths for the studied combinations were statistically significant, choosing the right cement for ceramics is critical.
- To define an optimal bonding protocol, each CAD-CAM material/luting composite must be individually studied and evaluated.
- There is an urgent need for randomized clinical trials or at least extensive well documented series of clinical cases.

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Annex 1. Articles data for difference of means and effect-size calculation.

author	material	surfacetreatment	aging	couplingcgentcdhesivecystem	lutingcement	test	sample	mean	sd	il	ul
Elsaka et al (2014)	Lava Ultimate	HF 9%	24 hours water storage	NO	Bifix SE	µTBS MPa	3	18.35	2.84	15.51	21.19
Elsaka et al (2014)	Lava Ultimate	Al2O3 50 µm	30 days water storage	NO	Bifix SE	µTBS MPa	3	13.49	3.4	10.09	16.89
Elsaka et al (2014)	Lava Ultimate	Al2O3 50 µm	24 hours water storage	NO	Bifix SE	µTBS MPa	3	16.93	3.66	13.27	20.59
Elsaka et al (2014)	Lava Ultimate	HF 9% + SILANE	24 hours water storage	Ultradent Silane	Bifix SE	µTBS MPa	3	19.21	3.87	15.34	23.08
Elsaka et al (2014)	Lava Ultimate	HF 9%	30 days water storage	NO	Bifix SE	µTBS MPa	3	13.45	3.34	10.11	16.79
Elsaka et al (2014)	Lava Ultimate	HF 9% + SILANE	30 days water storage	Ultradent Silane	Bifix SE	µTBS MPa	3	14.35	2.56	11.79	16.91
Elsaka et al (2014)	Lava Ultimate	Al2O3 50 µm + SILANE	30 days water storage	NO	Bifix SE	µTBS MPa	3	13.88	3.47	10.41	17.35
Elsaka et al (2014)	Lava Ultimate	No treatment	24 hours water storage	NO	Bifix SE	µTBS MPa	3	11.99	2.52	9.47	14.51
Elsaka et al (2014)	Lava Ultimate	Al2O3 50 µm + SILANE	24 hours water storage	Ultradent Silane	Bifix SE	µTBS MPa	3	18.82	3.69	15.13	22.51
Elsaka et al (2014)	Lava Ultimate	No treatment	30 days water storage	NO	Bifix SE	µTBS MPa	3	8.28	1.99	6.29	10.27
Elsaka et al (2014)	Vita Enamic	No treatment	24 hours water storage	NO	Bifix SE	µTBS MPa	3	18.67	3.1	15.57	21.77
Elsaka et al (2014)	Vita Enamic	HF 9% + SILANE	24 hours water storage	Ultradent Silane	Bifix SE	µTBS MPa	3	27.47	4.28	23.19	31.75
Elsaka et al (2014)	Vita Enamic	HF 9%	24 hours water storage	NO	Bifix SE	µTBS MPa	3	23.86	3.19	20.67	27.05
Elsaka et al (2014)	Vita Enamic	Al2O3 50 µm + SILANE	30 days water storage	Ultradent Silane	Bifix SE	µTBS MPa	3	19.48	3.18	16.3	22.66
Elsaka et al (2014)	Vita Enamic	No treatment	30 days water storage	NO	Bifix SE	µTBS MPa	3	12.67	2.13	10.54	14.8
Elsaka et al (2014)	Vita Enamic	Al2O3 50 µm + SILANE	24 hours water storage	Ultradent Silane	Bifix SE	µTBS MPa	3	24.95	3.79	21.16	28.74
Elsaka et al (2014)	Vita Enamic	HF 9%	30 days water storage	NO	Bifix SE	µTBS MPa	3	18.86	3.31	15.55	22.17
Elsaka et al (2014)	Vita Enamic	Al2O3 50 µm	24 hours water storage	NO	Bifix SE	µTBS MPa	3	21.87	3.75	18.12	25.62
Elsaka et al (2014)	Vita Enamic	Al2O3 50 µm	30 days water storage	NO	Bifix SE	µTBS MPa	3	16.71	3.42	13.29	20.13
Elsaka et al (2014)	Vita Enamic	HF 9% + SILANE	30 days water storage	Ultradent Silane	Bifix SE	µTBS MPa	3	22.21	3.04	19.17	25.25
Takahashi et al (2022)	Estelite block	Al2O3 50 µm	Thermocycling 30 000 cycles	HC Primer	Block HC Cem	SBS MPa	10	31.3	3.6	27.7	34.9
Takahashi et al (2022)	Estelite block	Al2O3 50 µm	Thermocycling 10 000 cycles	HC Primer	Block HC Cem	SBS MPa	10	34.8	3.3	31.5	38.1
Takahashi et al (2022)	Estelite block	Al2O3 50 µm	24h water storage	HC Primer	Block HC Cem	SBS MPa	10	24.1	2.3	21.8	26.4
Takahashi et al (2022)	Estelite block	Al2O3 50 µm	15 min water storage	HC Primer	Block HC Cem	SBS MPa	10	24.5	1	23.5	25.5
Takahashi et al (2022)	Katana Avencia	Al2O3 50 µm	Thermocycling 10 000 cycles	HC Primer	Block HC Cem	SBS MPa	10	23.5	2.9	20.6	26.4
Takahashi et al (2022)	Katana Avencia	Al2O3 50 µm	24h water storage	HC Primer	Block HC Cem	SBS MPa	10	24.6	3	21.6	27.6
Takahashi et al (2022)	Katana Avencia	Al2O3 50 µm	15 min water storage	HC Primer	Block HC Cem	SBS MPa	10	24.3	3	21.3	27.3
Takahashi et al (2022)	Katana Avencia	Al2O3 50 µm	Thermocycling 30 000 cycles	HC Primer	Block HC Cem	SBS MPa	10	21.6	2.5	19.1	24.1
Takahashi et al (2022)	Shofu Block HC	Al2O3 50 µm	15 min water storage	HC Primer	Block HC Cem	SBS MPa	10	25.5	2.5	23	28
Takahashi et al (2022)	Shofu Block HC	Al2O3 50 µm	24h water storage	HC Primer	Block HC Cem	SBS MPa	10	29.3	2.5	26.8	31.8
Takahashi et al (2022)	Shofu Block HC	Al2O3 50 µm	Thermocycling 30 000 cycles	HC Primer	Block HC Cem	SBS MPa	10	19.7	2.7	17	22.4
Takahashi et al (2022)	Shofu Block HC	Al2O3 50 µm	Thermocycling 10 000 cycles	HC Primer	Block HC Cem	SBS MPa	10	26.5	3.5	23	30
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	Visiolink	Clearfil SA	TBS MPa	20	17.3	5.3	12	22.6
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	VP Connect	Clearfil SA	TBS MPa	20	17.9	4.6	13.3	22.5
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	Visiolink	Clearfil SA	TBS MPa	20	28.8	6.3	22.5	35.1
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	NO	Clearfil SA	TBS MPa	20	0	0	0	0
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	VP Connect	Clearfil SA	TBS MPa	20	25.6	4.3	21.3	29.9
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	NO	Clearfil SA	TBS MPa	20	7.1	7.8	-0.7	14.9
Malysa et al (2022)	IPS Empress CAD	HF 5%	No Thermal Cycling	NO	Maxcem	SBS MPa	12	15.48	1.158	14.32	16.64
Malysa et al (2022)	IPS Empress CAD	HF 5%	Thermal Cycling	NO	Maxcem	SBS MPa	12	3.37	0.229	3.14	3.6
Malysa et al (2022)	IPS Empress CAD	HF 5%	.	NO	Maxcem	SBS MPa	12	12.11	1.274	10.84	13.38
Malysa et al (2022)	IPS e max. Zircad	HF 5%	Thermal Cycling	NO	Maxcem	SBS MPa	12	2.32	0.182	2.14	2.5
Malysa et al (2022)	IPS e max. Zircad	HF 5%	No Thermal Cycling	NO	Maxcem	SBS MPa	12	13.29	1.185	12.1	14.47
Malysa et al (2022)	IPS e max. Zircad	HF 5%	.	NO	Maxcem	SBS MPa	12	10.97	1.212	9.76	12.18
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	No Thermal Cycling	NO	Maxcem	SBS MPa	12	8.428	0.867	7.56	9.3
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	.	NO	Maxcem	SBS MPa	12	6.37	0.739	5.63	7.11
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	Thermal Cycling	NO	Maxcem	SBS MPa	12	2.058	0.445	1.61	2.5
Abdou et al (2021)	Katana Avencia	PA 37%	1 week water storage	Kerr silane Primer	Nexus 3	µTBS MPa	5	26.1	4.6	21.5	30.7
Abdou et al (2021)	Katana Avencia	PA 37%	1 week water storage	Kerr silane Primer	Nexus 3	µTBS MPa	5	27.7	3.8	23.9	31.5
Abdou et al (2021)	Katana Avencia	PA 37%	1 hour water storage	Kerr silane Primer	Nexus 3	µTBS MPa	5	27.2	4.1	23.1	31.3
Abdou et al (2021)	Katana Avencia	PA 37%	1 hour water storage	Kerr silane Primer	Nexus 3	µTBS MPa	5	29.3	2.2	27.1	31.5
Malysa et al (2022)	IPS Empress CAD	HF 5%	.	NO	Panavia AS	SBS MPa	12	13.96	1.924	12.04	15.88
Malysa et al (2022)	IPS Empress CAD	HF 5%	Thermal Cycling	NO	Panavia AS	SBS MPa	12	2.98	0.667	2.31	3.65
Malysa et al (2022)	IPS Empress CAD	HF 5%	No Thermal cycling	NO	Panavia AS	SBS MPa	12	16.94	1.533	15.41	18.47
Malysa et al (2022)	IPS e max. Zircad	HF 5%	.	NO	Panavia AS	SBS MPa	12	15.77	1.424	14.35	17.19
Malysa et al (2022)	IPS e max. Zircad	HF 5%	No Thermal cycling	NO	Panavia AS	SBS MPa	12	18.31	1.357	16.95	19.67
Malysa et al (2022)	IPS e max. Zircad	HF 5%	Thermal Cycling	NO	Panavia AS	SBS MPa	12	2.55	0.55	2	3.1
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	.	NO	Panavia AS	SBS MPa	12	6.679	1.162	5.52	7.84
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	No Thermal cycling	NO	Panavia AS	SBS MPa	12	9.888	0.926	8.96	10.81
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	Thermal Cycling	NO	Panavia AS	SBS MPa	12	3.209	0.588	2.62	3.8
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm	No water storage	NO	Panavia SA Cement	µTBS MPa	3	66.02	10.67	55.35	76.69
Higashi et al (2016)	Katana Avencia	No treatment	3 months water storage	NO	Panavia SA Cement	µTBS MPa	3	26.05	7.66	18.39	33.71
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm	3 months water storage	NO	Panavia SA Cement	µTBS MPa	3	65.75	15.37	50.38	81.12
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm + SILANE	No water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	59.31	13.44	45.87	72.75
Higashi et al (2016)	Katana Avencia	No treatment	No water storage	NO	Panavia SA Cement	µTBS MPa	3	40.42	11.36	29.06	51.78
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm + SILANE	3 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	60.04	15.93	44.11	75.97
Higashi et al (2016)	Katana Avencia	SILANE	No water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	70.95	11.9	59.05	82.85
Higashi et al (2016)	Katana Avencia	SILANE	3 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	55.71	9.91	45.8	65.62
Higashi et al (2016)	Katana Avencia	No treatment	1 month water storage	NO	Panavia SA Cement	µTBS MPa	3	33.02	16.45	16.57	49.47
Higashi et al (2016)	Katana Avencia	SILANE	6 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	54.24	11.44	42.8	65.68
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm + SILANE	1 month water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	55.59	14.23	41.36	69.82
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm	6 months water storage	NO	Panavia SA Cement	µTBS MPa	3	59.44	20.4	39.04	79.84
Higashi et al (2016)	Katana Avencia	SILANE	1 month water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	64.29	15.87	48.42	80.16
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm	1 month water storage	NO	Panavia SA Cement	µTBS MPa	3	68.46	19.06	49.4	87.52
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm + SILANE	6 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	56.44	17.88	38.56	74.32
Higashi et al (2016)	Katana Avencia	No treatment	6 months water storage	NO	Panavia SA Cement	µTBS MPa	3	25.03	12.34	12.69	37.37
Kawaguchi et al (2016)	Katana Avencia	PA 40%	6 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	46.1	14.3	31.8	60.4
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning + PA 40%	No water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	63.9	10.9	53	74.8
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning	1 month water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	55.3	9.4	45.9	64.7
Kawaguchi et al (2016)	Katana Avencia	PA 40%	1 month water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	62.4	8.2	54.2	70.6
Kawaguchi et al (2016)	Katana Avencia	PA 40%	No water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	62.6	9.9	52.7	72.5
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning + PA 40%	3 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	46.7	10.9	35.8	57.6
Kawaguchi et al (2016)	Katana Avencia	No cleaning treatment	3 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	54	10.9	43.1	64.9
Kawaguchi et al (2016)	Katana Avencia	No cleaning treatment	6 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	48.8	10	38.8	58.8
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning	3 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	55.8	11.3	44.5	67.1
Kawaguchi et al (2016)	Katana Avencia	PA 40%	3 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	49.5	16.5	33	66
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning + PA 40%	1 month water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	62.9	12.5	50.4	75.4
Kawaguchi et al (2016)	Katana Avencia	No cleaning treatment	1 month water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	60.9	11	49.9	71.9
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning	No water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	62.6	9.9	52.7	72.5
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning	6 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	48.8	10.5	38.3	59.3
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning + PA 40%	6 months water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	46.7	13.1	33.6	59.8
Kawaguchi et al (2016)	Katana Avencia	No cleaning treatment	No water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement	µTBS MPa	3	62.7	10.4	52.3	73.1
Oda et al (2021)	Katana Avencia	Al2O3 50 µm	24 hours water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement Plus	µTBS MPa	5	37.2	8.3	28.9	45.5
Oda et al (2021)	Katana Avencia	Al2O3 50 µm	24 hours water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement Plus	µTBS MPa	5	17	3.7	13.3	20.7
Oda et al (2021)	Katana Avencia	Al2O3 50 µm	24 hours water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement Plus	µTBS MPa	5	40.3	9.8	30.5	50.1
Oda et al (2021)	Katana Avencia	Al2O3 50 µm	24 hours water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement Plus	µTBS MPa	5	23.9	6.8	17.1	30.7
Oda et al (2021)	Katana Avencia	Al2O3 50 µm	24 hours water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement Universal	µTBS MPa	5	14.7	5.7	9	20.4
Oda et al (2021)	Katana Avencia	Al2O3 50 µm	24 hours water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement Universal	µTBS MPa	5	24.5	6.2	18.3	30.7
Oda et al (2021)	Katana Avencia	Al2O3 50 µm	24 hours water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement Universal	µTBS MPa	5	34.2	8.1	26.1	42.3
Oda et al (2021)	Katana Avencia	Al2O3 50 µm	24 hours water storage	Clearfil Ceramic Primer Plus	Panavia SA Cement Universal	µTBS MPa	5	29.5	7	22.5	36.5
Takahashi et al (2022)	Estelite block	Al2O3 50 µm	Thermocycling 30 000 cycles	HC Primer	Panavia SA Cement Universal	SBS MPa	10	14.7	3	11.7	17.7
Takahashi et al (2022)	Estelite block	Al2O3 50 µm	Thermocycling 10 000 cycles	HC Primer	Panavia SA Cement Universal	SBS MPa	10	17.7	3.4	14.3	21.1
Takahashi et al (2022)	Estelite block	Al2O3 50 µm	15 min water storage	HC Primer	Panavia SA Cement Universal	SBS MPa	10	12.1	1.2	10.9	13.3
Takahashi et al (2022)	Estelite block	Al2O3 50 µm	24h water storage	HC Primer	Panavia SA Cement Universal	SBS MPa	10	17.9	3.4	14.5	21.3
Takahashi et al (2022)	Katana Avencia	Al2O3 50 µm	Thermocycling 30 000 cycles	HC Primer	Panavia SA Cement Universal	SBS MPa	10	18.6	2.2	16.4	20.8
Takahashi et al (2022)	Katana Avencia	Al2O3 50 µm	24h water storage	HC Primer	Panavia SA Cement Universal	SBS MPa	10	19.9	1.8	18.1	21.7
Takahashi et al (2022)	Katana Avencia	Al2O3 50 µm	15 min water storage	HC Primer	Panavia SA Cement Universal	SBS MPa	10	15.6	1.9	13.7	17.5
Takahashi et al (2022)	Katana Avencia	Al2O3 50 µm	Thermocycling 10 000 cycles	HC Primer	Panavia SA Cement Universal	SBS MPa	10	19.8	1.9	17.9	21.7
Takahashi et al (2022)	Shofu Block HC	Al2O3 50 µm	15 min water storage	HC Primer	Panavia SA Cement Universal	SBS MPa	10	14.5	1.5	13	16
Takahashi et al (2022)	Shofu Block HC	Al2O3 50 µm	Thermocycling 10 000 cycles	HC Primer	Panavia SA Cement Universal	SBS MPa	10	19.8	3.5	16.3	23.3
Takahashi et al (2022)	Shofu Block HC	Al2O3 50 µm	Thermocycling 30 000 cycles	HC Primer	Panavia SA Cement Universal	SBS MPa	10	18.5	2.7	15.8	21.2
Takahashi et al (2022)	Shofu Block HC	Al2O3 50 µm	24h water storage	HC Primer	Panavia SA Cement Universal	SBS MPa	10	16.1	1.8	14.3	17.9
Abdou et al (2021)	Katana Avencia	Al2O3 50 µm	1 hour water storage	Clearfil Universal Bond Quick	Panavia V5	µTBS MPa	5	48.3	4.4	43.9	52.7
Abdou et al (2021)	Katana Avencia	Al2O3 50 µm	1 hour water storage	Clearfil Universal Bond Quick	Panavia V5	µTBS MPa	5	39.4	2.8	36.6	42.2
Abdou et al (2021)	Katana Avencia	Al2O3 50 µm	1 week water storage	Clearfil Universal Bond Quick	Panavia V5	µTBS MPa	5	29.3	2.4	26.9	31.7
Abdou et al (2021)	Katana Avencia	Al2O3 50 µm	1 week water storage	Clearfil Universal Bond Quick	Panavia V5	µTBS MPa	5	37.2	1.7	35.5	38.9
Higashi et al (2016)	Katana Avencia	No treatment	1 month water storage	NO	Panavia v5	µTBS MPa	3	24.02	9.59	14.43	33.61
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm	6 months water storage	NO	Panavia v5	µTBS MPa	3	82.41	27.64	54.77	110.05
Higashi et al (2016)	Katana Avencia	No treatment	3 months water storage	NO	Panavia v5	µTBS MPa	3	23.15	12.39	10.76	35.54
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm	1 month water storage	NO	Panavia v5	µTBS MPa	3	63.51	13.37	50.14	76.88
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm + SILANE	1 month water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	84.24	11.43	72.81	95.67
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm	No water storage	NO	Panavia v5	µTBS MPa	3	78.4	12.65	65.75	91.05
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm + SILANE	3 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	80.73	18.22	62.51	98.95
Higashi et al (2016)	Katana Avencia	SILANE	6 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	59.6	13.1	46.5	72.7
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm + SILANE	No water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	86.98	6.4	80.58	93.38
Higashi et al (2016)	Katana Avencia	SILANE	3 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	66.73	13.65	53.08	80.38
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm + SILANE	6 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	79.42	11.42	68	90.84
Higashi et al (2016)	Katana Avencia	SILANE	No water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	82.51	12.36	70.15	94.87
Higashi et al (2016)	Katana Avencia	SILANE	1 month water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	78.59	13.57	65.02	92.16
Higashi et al (2016)	Katana Avencia	No treatment	No water storage	NO	Panavia v5	µTBS MPa	3	37.19	13.33	23.86	50.52
Higashi et al (2016)	Katana Avencia	No treatment	6 months water storage	NO	Panavia v5	µTBS MPa	3	25.1	13.57	11.53	38.67
Higashi et al (2016)	Katana Avencia	Al2O3 50 µm	3 months water storage	NO	Panavia v5	µTBS MPa	3	76.18	15.53	60.65	91.71
Kawaguchi et al (2016)	Katana Avencia	PA 40%	No water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	81.1	7.6	73.5	88.7
Kawaguchi et al (2016)	Katana Avencia	PA 40%	6 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	70	13.9	56.1	83.9
Kawaguchi et al (2016)	Katana Avencia	No cleaning treatment	1 month water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	98.1	11.5	86.6	109.6
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning + PA 40%	6 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	65.9	14.6	51.3	80.5
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning + PA 40%	3 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	70.1	10	60.1	80.1
Kawaguchi et al (2016)	Katana Avencia	PA 40%	3 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	69.6	13.9	55.7	83.5
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning	6 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	64.6	9	55.6	73.6
Kawaguchi et al (2016)	Katana Avencia	PA 40%	1 month water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	70.1	11.6	58.5	81.7
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning + PA 40%	1 month water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	70	9.8	60.2	79.8
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning	3 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	72.7	10.4	62.3	83.1
Kawaguchi et al (2016)	Katana Avencia	UC + AC	No water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	82.9	11.7	71.2	94.6
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning	1 month water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	60	9.3	50.7	69.3
Kawaguchi et al (2016)	Katana Avencia	Ultrassonic cleaning	No water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	87.6	8.9	78.7	96.5
Kawaguchi et al (2016)	Katana Avencia	No cleaning treatment	No water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	96.5	10.3	86.2	106.8
Kawaguchi et al (2016)	Katana Avencia	No cleaning treatment	6 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	78	14.4	63.6	92.4
Kawaguchi et al (2016)	Katana Avencia	No cleaning treatment	3 months water storage	Clearfil Ceramic Primer Plus	Panavia v5	µTBS MPa	3	89.7	11.8	77.9	101.5
Malysa et al (2022)	IPS Empress CAD	HF 5%	Thermal Cycling	NO	Panavia V5	SBS MPa	12	16.84	0.844	16	17.68
Malysa et al (2022)	IPS Empress CAD	HF 5%	No Thermal cycling	NO	Panavia V5	SBS MPa	12	20.33	0.787	19.54	21.12
Malysa et al (2022)	IPS Empress CAD	HF 5%	.	NO	Panavia V5	SBS MPa	12	3.488	1.041	2.45	4.53
Malysa et al (2022)	IPS e max. Zircad	HF 5%	.	NO	Panavia V5	SBS MPa	12	3.632	0.875	2.76	4.51
Malysa et al (2022)	IPS e max. Zircad	HF 5%	Thermal Cycling	NO	Panavia V5	SBS MPa	12	7.6	0.765	6.83	8.37
Malysa et al (2022)	IPS e max. Zircad	HF 5%	No Thermal cycling	NO	Panavia V5	SBS MPa	12	11.23	0.475	10.76	11.71
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	.	NO	Panavia V5	SBS MPa	12	3.059	0.952	2.11	4.01
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	No Thermal cycling	NO	Panavia V5	SBS MPa	12	22.5	0.69	21.81	23.19
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	Thermal Cycling	NO	Panavia V5	SBS MPa	12	19.45	0.564	18.89	20.01
Bayazit et al (2019)	Lava Ultimate	HA 9.5% % + UA	24 hours 37oC water storage	Single Bond Universal	Rely X U200	µTBS MPa	15	38.7	6.4	32.3	45.1
Bayazit et al (2019)	Lava Ultimate	Al2O3 50µm + UA	24 hours 37oC water storage	Single Bond Universal	Rely X U200	µTBS MPa	15	31.7	4.5	27.2	36.2
Bayazit et al (2019)	Lava Ultimate	NO	24 hours 37oC water storage	NO	Rely X U200	µTBS MPa	15	19.1	4.9	14.2	24
Bayazit et al (2019)	Vita Enamic	NO	24 hours 37oC water storage	NO	Rely X U200	µTBS MPa	15	17.6	4.6	13	22.2
Bayazit et al (2019)	Vita Enamic	Al2O3 50µm + UA	24 hours 37oC water storage	Single Bond Universal	Rely X U200	µTBS MPa	15	30.8	5.4	25.4	36.2
Bayazit et al (2019)	Vita Enamic	HA 9.5% % + UA	24 hours 37oC water storage	Single Bond Universal	Rely X U200	µTBS MPa	15	23.7	4.3	19.4	28
Malysa et al (2022)	IPS Empress CAD	HF 5%	.	NO	Rely X U200	SBS MPa	12	11.77	1.895	9.88	13.66
Malysa et al (2022)	IPS Empress CAD	HF 5%	No Thermal cycling	NO	Rely X U200	SBS MPa	12	15.14	1.953	13.19	17.09
Malysa et al (2022)	IPS Empress CAD	HF 5%	Thermal Cycling	NO	Rely X U200	SBS MPa	12	3.36	0.26	3.1	3.62
Malysa et al (2022)	IPS e max. Zircad	HF 5% + PA 37%	No Thermal cycling	NO	Rely X U200	SBS MPa	12	22.73	1.148	21.58	23.88
Malysa et al (2022)	IPS e max. Zircad	HF 5%	Thermal Cycling	NO	Rely X U200	SBS MPa	12	1.95	0.52	1.43	2.47
Malysa et al (2022)	IPS e max. Zircad	HF 5%	.	NO	Rely X U200	SBS MPa	12	20.78	1.196	19.58	21.98
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	.	NO	Rely X U200	SBS MPa	12	5.092	0.908	4.18	6
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	Thermal Cycling	NO	Rely X U200	SBS MPa	12	3.135	0.595	2.54	3.73
Malysa et al (2022)	IPS e.max CAD	HF 5% + PA 37%	No Thermal cycling	NO	Rely X U200	SBS MPa	12	8.228	0.696	7.53	8.92
Ustun et al (2021)	Cerasmart	HF 5%	Thermal aging	Ultradent Silane	Rely X U200	µSBS MPa	7	5.62	0.29	5.33	5.91
Ustun et al (2021)	Cerasmart	HF 5%	No Thermal aging	Ultradent Silane	Rely X U200	µSBS MPa	7	7.48	0.32	7.16	7.8
Ustun et al (2021)	Vita Enamic	HF 5%	Thermal aging	Ultradent Silane	Rely X U200	µSBS MPa	7	4.69	0.21	4.48	4.9
Ustun et al (2021)	Vita Enamic	HF 5%	No Thermal aging	Ultradent Silane	Rely X U200	µSBS MPa	7	7.14	0.45	6.69	7.59
Ustun et al (2021)	Vita suprinity	HF 5%	No Thermal aging	Ultradent Silane	Rely X U200	µSBS MPa	7	10.27	0.54	9.73	10.81
Ustun et al (2021)	Vita suprinity	HF 5%	Thermal aging	Ultradent Silane	Rely X U200	µSBS MPa	7	8.46	0.33	8.13	8.79
Abdou et al (2021)	Katana Avencia	Al2O3 50 µm	1 hour water storage	Scothbond Universal Adhesive	Rely X Ultimate	µTBS MPa	5	36.4	2.4	34	38.8
Abdou et al (2021)	Katana Avencia	Al2O3 50 µm	1 week water storage	Scothbond Universal Adhesive	Rely X Ultimate	µTBS MPa	5	31.3	2.5	28.8	33.8
Abdou et al (2021)	Katana Avencia	Al2O3 50 µm	1 week water storage	Scothbond Universal Adhesive	Rely X Ultimate	µTBS MPa	5	27.7	3.8	23.9	31.5
Abdou et al (2021)	Katana Avencia	Al2O3 50 µm	1 hour water storage	Scothbond Universal Adhesive	Rely X Ultimate	µTBS MPa	5	44	3.4	40.6	47.4
Ceci et al (2016)	Lava Ultimate	Dentin treatment with Glycine Powder	24 hours water storage	Scotchbond Universal Adhesive	Rely X Ultimate	µSBS MPa	5	9.98	1.94	8.04	11.92
Ceci et al (2016)	Lava Ultimate	Dentin treatment with Glycine Powder + Al2O3	24 hours water storage	Scotchbond Universal Adhesive	Rely X Ultimate	µSBS MPa	5	17.88	1.44	16.44	19.32
Ceci et al (2016)	Lava Ultimate	No dentin treatment + Al2O3 50 µm + 35% PA	24 hours water storage	Scotchbond Universal Adhesive	Rely X Ultimate	µSBS MPa	5	11.98	2.91	9.07	14.89
Ceci et al (2016)	Lava Ultimate	No dentin treatment + Al2O3 50 µm	24 hours water storage	Scotchbond Universal Adhesive	Rely X Ultimate	µSBS MPa	5	16.58	3.87	12.71	20.45
Poggio et al (2016)	Lava Ultimate	PA 37%	24h water storage	Scotchbond Universal Adhesive	Rely X Ultimate	SBS MPa	10	11.98	2.91	9.07	14.89
Poggio et al (2016)	Lava Ultimate	No treatment	24h water storage	Scotchbond Universal Adhesive	Rely X Ultimate	SBS MPa	10	16.58	3.87	12.71	20.45
Ustun et al (2021)	Cerasmart	HF 5%	Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	7.57	0.37	7.2	7.94
Ustun et al (2021)	Cerasmart	HF 5%	No Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	9.89	0.32	9.57	10.21
Ustun et al (2021)	Cerasmart	PA 37%	No Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	8.05	0.26	7.79	8.31
Ustun et al (2021)	Cerasmart	PA 37%	Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	6.29	0.33	5.96	6.62
Ustun et al (2021)	Vita Enamic	PA 37%	Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	4.59	0.41	4.18	5
Ustun et al (2021)	Vita Enamic	PA 37%	No Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	7.14	0.12	7.02	7.26
Ustun et al (2021)	Vita Enamic	HF 5%	Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	6.37	0.33	6.04	6.7
Ustun et al (2021)	Vita Enamic	HF 5%	No Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	8.54	0.31	8.23	8.85
Ustun et al (2021)	Vita suprinity	PA 37%	Thermal aging	adent Silane + Single Bond Universal Adhesive	Rely X Ultimate	µSBS MPa	7	8.34	0.3	8.04	8.64
Ustun et al (2021)	Vita suprinity	PA 37%	No Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	10.9	0.34	10.56	11.24
Ustun et al (2021)	Vita suprinity	HF 5%	Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	5.48	0.35	5.13	5.83
Ustun et al (2021)	Vita suprinity	HF 5%	No Thermal aging	Ultradent Silane	Rely X Ultimate	µSBS MPa	7	7.47	0.46	7.01	7.93
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	Visiolink	Rely X Unicem	TBS MPa	20	29	6.3	22.7	35.3
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	NO	Rely X Unicem	TBS MPa	20	2	6.2	-4.2	8.2
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	NO	Rely X Unicem	TBS MPa	20	10.2	11.9	-1.7	22.1
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	Visiolink	Rely X Unicem	TBS MPa	20	17.6	4.1	13.5	21.7
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	VP Connect	Rely X Unicem	TBS MPa	20	2.1	4.1	-2	6.2
Liebermann et al (2013)	ArtBlock temp	Al2O3 50 µm	24 h water storage + 5000 cycles	VP Connect	Rely X Unicem	TBS MPa	20	0	0	0	0
Ceci et al (2016)	Lava Ultimate	No dentin treatment + Al2O3 50 µm	24 hours water storage	NO	Rely X Unicem 2	µSBS MPa	5	3.3	0.39	2.91	3.69
Ceci et al (2016)	Lava Ultimate	Dentin treatment with Glycine Powder + Al2O3	24 hours water storage	NO	Rely X Unicem 2	µSBS MPa	5	10.4	0.87	9.53	11.27
Poggio et al (2016)	Lava Ultimate	No treatment	24h water storage	NO	Rely X Unicem 2	SBS MPa	10	4.54	0.84	3.7	5.38
Bayazit et al (2019)	Lava Ultimate	Al2O3 50 µm + UA	24 hours 37oC water storage	Single Bond Universal	Set PP	µTBS MPa	15	25.3	5	20.3	30.3
Bayazit et al (2019)	Lava Ultimate	NO	24 hours 37oC water storage	NO	Set PP	µTBS MPa	15	22.1	4.6	17.5	26.7
Bayazit et al (2019)	Lava Ultimate	HA 9.5% % + UA	24 hours 37oC water storage	Single Bond Universal	Set PP	µTBS MPa	15	28.3	4.2	24.1	32.5
Bayazit et al (2019)	Vita Enamic	Al2O3 50 µm + UA	24 hours 37oC water storage	Single Bond Universal	Set PP	µTBS MPa	15	18.9	5.9	13	24.8
Bayazit et al (2019)	Vita Enamic	HA 9.5% % + UA	24 hours 37oC water storage	Single Bond Universal	Set PP	µTBS MPa	15	20.9	3.8	17.1	24.7
Bayazit et al (2019)	Vita Enamic	NO	24 hours 37oC water storage	NO	Set PP	µTBS MPa	15	19.8	2.8	17	22.6