Saudi Dental Journal (2022) **34**, 259–269

King Saud University

Saudi Dental Journal

www.ksu.edu.sa
www.sciencedirect.com

SAUDI DENTAL SOCIETY

REVIEW ARTICLE

Bonding CAD/CAM materials with current adhesive systems: An overview

Ali Y. Alsaeed

Certified in Advanced Operative and Adhesive Dentistry, Specialized in Restorative and Biomaterials, Department at King Khalid University, Abha, Saudi Arabia

Received 25 July 2021; revised 17 March 2022; accepted 23 March 2022
Available online 9 April 2022

KEYWORDS

CAD-CAM;
Adhesion;
Resin cements;
Ceramic;
Enamel;
Dentin;
Acid etch;
Zirconia

Abstract *Objective:* Overview of the updated literature on the classification of adhesives systems and CAD/CAM materials with clinical guidelines to condition various surfaces for bonding to the tooth structure.

Data sources: Searches were conducted in MEDLINE, EMBASE, PubMed, Web of Science, Scopus, Cochrane Library, and Google Scholar using specific keywords.

Results: 240 papers were revised, 150 articles were excluded, and 90 were eligible for the review. Most studies concluded the essentiality of bonding E-max, zirconia, and hybrid materials to enhance fracture toughness and fatigue resistance. The success of ceramic bonding depends on the microstructure and surface treatment of the materials. The proper treatment of the intaglio starts with using alumina oxide or hydrofluoric acid. This initial treatment could be followed by monobond salinization, which improves the chemical adhesion. Zirconia-based ceramics have grown lately and become the most prescribed for posterior and anterior teeth. Zirconia can be bonded to the tooth structure using the APC concept and 10 MDP promoting primers. Three hundred adhesive resin systems are currently available in the market, and each is different in chemical composition and clinical bonding strength. Of the three hundred systems, the total-etch system remains the gold standard, especially on the enamel surface. The self-etch adhesive system is favorable on dentin due to lowering the postoperative sensitivity. A new generation of dentin adhesives, called universal or multi-mode adhesives. This system has become popular and can be used either as etch-and-rinse or self-etch adhesives.

Conclusion: The chemistry of adhesive systems has changed across generations. The variation of dental tissue is the decisive factor in selecting adhesive systems, resin cement, and ceramic materials.

E-mail address: dralsaeed2030@gmail.com

Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

https://doi.org/10.1016/j.sdentj.2022.03.005

Moreover, a reliable bonding strength necessitates a perfect surface treatment and bonding promoter for tooth and CAD/CAM materials.

Contents

1. Introduction and background

Adhesion is an ideal approach for restorative treatment. The significant improvement of bonding agents and resin cement creates an excellent marginal seal, upgrades the endurance rate of restorations, and minimizes the aggressivity of tooth preparation (Sofan et al., 2017).

In 1955, M. Buonocore improved adhesion to dental tissue by exposing the enamel surface to 38% orthophosphoric acid. He and Matsui proposed the usage of 37% phosphoric acid to increase the microscopic surface area for resin retention (Pashley et al., 2011). Nakabayashi and Fusayama discovered the adhesion to dentin by introducing the compatibility between adhesive resin and dentinal tubules, named hybrid layer (Van Meerbeek et al., 2011).

Forming a hybridization layer occurs by the diffusion of monomers through the capillary attraction that crosslinks the resin into the collagen of dentin, which necessitates surface conditioning either mechanically or chemically (Neimar Sartori, 2017).

Dental adhesives contain resin monomers, organic solvents, inhibitors, initiators, and fillers. Organizations and researchers have improved adhesive agents to maximize their bonding strength by using fewer bottles. Thus, at present, over 300 adhesive systems have been manufactured (Van Landuyt et al., 2007).

The longevity of the resin in the interface varies depending on the dental tissue. Enamel is a suitable substrate because of its inorganic composition, which contains less water and remains an ideal substrate for resin monomers (Susin et al., 2007).

Restoring the shape, color, and function of the teeth is still challenging. However, the development of the CAD/CAM materials eases the treatment of decayed, fractured, and eroded teeth due to the unique features of ceramic materials (Angeletaki et al., 2016).

Adhesion to CAD/CAM restorations was the reason to outspread the ceramic throughout the world. They became the first choice for dentists due to their biocompatibility, aesthetics, and hardness (Elsaka, 2014). Several materials are presently available for the digital process, and they are accessible in blocks or disks. These materials are utilized in restorative dentistry, dental implantology, and complex prosthetics therapy. Selecting the appropriate material requires close attention to the occlusion and habits of the patient. Manufacturers and researchers produce various CAD/CAM materials to meet patient expectations regarding esthetics and longevity. Thus, CAD/CAM materials have been synthesized with a high modulus of elasticity, hardness, crake toughness, wear resistance, and some demonstrate resilience and repairability (Arnetzl and Arnetzl, 2015).

Ceramic materials are different in their compositions and mechanical properties, which becomes easy to use with

CAD/CAM-based machines. Resins blocks are very valuable due to their simplicity in fabrication although glass-ceramics have a superior aesthetic appearance and better mechanical properties. Hybrid ceramics combine ceramic and resin, offer both ceramic and composite features, and display superior mechanical properties (Ruse and Sadoun, 2014). In general, ceramic materials are categorized into glass, polycrystalline, and resin-matrix materials (Gresnigt et al., 2015).

Today, professionals are passionate about using CAD/CAM technology, software, and adhesive systems for many reasons. A primary advantage of the technology is that is facilitates quick treatment. Hence, the primary purpose of this paper is to review the updated literature regarding the scientific guidelines of clinical bonding protocols, the differences between CAD/CAM materials, and the types of adhesive resin cement.

2. Material and methods

2.1. Information source and search

This review started in May 2020 until August 2020. An electronic search was conducted through Medical Subject Heading (MeSH) terms, literature libraries, and free-text words. The search aimed to retrieve in vitro, in vivo studies, and a systematic review that explained the classification of ceramic materials, adhesive systems, and the bonding protocols of CAD/CAM materials to the tooth structure. Three reviewers screened the eligible papers by two methods: either directly through literature libraries or indirectly through article references. The complete text was analyzed by two reviewers to decide the final collection using SPSS IBM software Version 27 for Interobserver agreement (Cohen's kappa). The reviewers discussed and resolved disagreements regarding selection among themselves before proceeding.

2.2. Eligibility criteria

Articles eligible for inclusion were considering CAD/CAM materials and adhesion protocols, in vitro and in vivo studies that evaluating the toughness and fatigue resistance of ceramic materials using CAD/CAM technology, papers focusing on micro-and macro-shear in addition to micro-and macro-tensile bonding strength, and reviews that compared a variety of cement on enamel or dentine and involving ceramic/cement/human tooth complex.

The articles meeting one or more of the following criteria were excluded: Papers aimed at studying the fracture resistance of implant-supported ceramic restorations, papers focusing on digital impressions, or excluding the bonding strength from the methodology, articles with less than 30 samples in their experiments or no control group, studies that examined the strength of the materials using cementation instead of bonding.

3. Results of the research

3.1. Study selection

Fig. 1 illustrates the methodology for the electronic searches that retrieved 240 non-duplicate articles; a total of 90 studies were included in this review. Through Medline (PubMed) and Embase, 122 articles were extracted after analyzing their abstracts. Web of Science and Scopus provided 25 articles while Cochrane and Google Scholar presented 93, while 25 studies were not relevant and out of scope of this review. There were 35 papers that did not meet the inclusion criteria. There

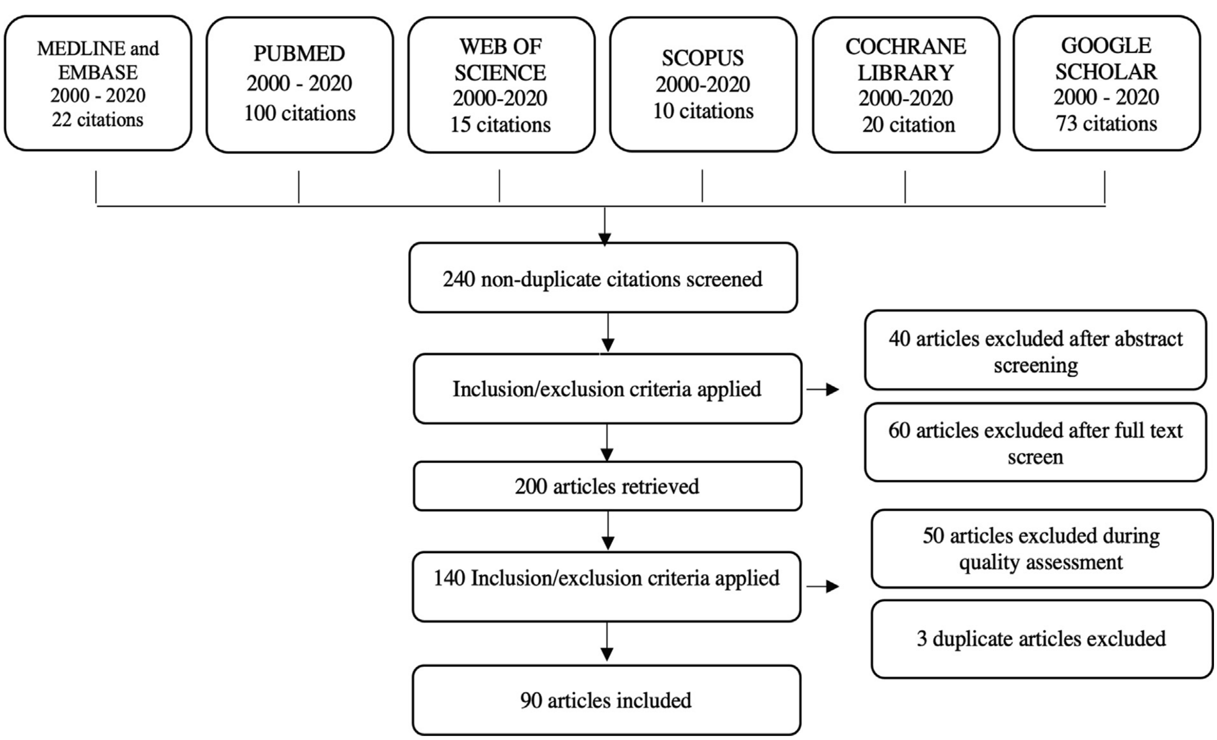

Fig. 1 PRISMA flow diagram.PRISM, Preferred Reporting Items for Systematic Review.

were 50 articles that did not test the bonding strength, and 40 articles were excluded due to insufficient sample size, no control group, and methodological quality.

Regarding in vitro or in vivo studies, the most common reasons for exclusion were the absence of adhesion protocol, the sample preparation methods, or the lack of clarity in bonding tests. The papers that studied ceramic materials and did not show the intaglio surface treatment or the types of resin cement that were discarded.

The result of Cohen's kappa coefficient for inter-rater reliability was 0.80 regarding the final inclusion of suggested studies after complete text analysis, which is generally considered a strong level of agreement (Landis and Koch, 1977).

3.2. Modern dental adhesive systems

The concept of adhesion improved the treatment approach in restorative therapy. Bonding to tooth surface has become essential in most dental treatments as orthodontic brackets, dental posts, and ceramic materials. The primary purpose of bonding is the creation of micro-mechanical retention between CAD/CAM materials and the tooth structure. It may be achieved chemically, mechanically, or through a combination of both (Piwowarczyk et al., 2004).

The adhesive systems are comprised of resin monomers, curing initiators, inhibitors, stabilizers, solvents, and fillers. Monomers are spread over a substrate to ensure that the resin cement adheres to the tooth structure (Perdigao, 2007). Consequently, they consist of hydrophilic and hydrophobic components, which promote wettability with the dental structure and interact with resin materials, respectively (Van Landuyt et al., 2007).

The three main components of the adhesive system are etchant, primer, and adhesive resin (Bedran-Russo et al., 2017). The adhesion process starts with the application of a surface conditioning agent (typically 35–37% phosphoric acid) to eliminate the smear layer from the tooth surface and make it rougher. Next, the primer is applied, as it acts as a bio-functional agent to enhance the attachment between enamel/-dentin and resin materials (Peumans et al., 2010). Finally, the adhesive (comprised of a monomer, photo-initiator, and fillers) is used. Depending on their type (self-cure, light-cure, or dual-cure), adhesives may need to be polymerized. Currently used adhesive systems can be categorized into total-etch, self-etch, and universal systems based on the smear layer removal, chemical reaction, and the steps involved in their application. However, how to select the ideal adhesive remains debated.

Table 1 Summary of Modern Dental Adhesive Systems.

Generation	Brand name	Polymerization
A		
4th generation Three-steps etch-rinse	All-Bond 2	Dual cured
	Optibond FL	Light cured
	Adper Scotchbond Multi-Purpose plus	Light + Dual cured
	FL Bond	Light cured
	Scotchbond Multi-Purpose	Light cured
	Bond-it	Light + Dual cured
B		
5th generation Two-steps etch-rinse	Scotchbond 1 [Single Bond]	Light cured
	Prime&Bond NT	Dual cured
	Single Bond 2	Light cured
	All bond plus	Light cured
	ExciTE F	Light cured
C		
6th generation Two-steps self-etch	Adper Scotchbond SE	Light cured
	FL bond II	Light cured
	Clearfil Protect Bond	Light cured
D		
7th generation All-in-one	OptiBond All-In-One	Light cured
	Clearfil S3 Bond Plus	Light cured
	Adper Easy one	Light cured

Total-etch systems contain three components (etchant, primer, and resin), usually packaged in separate bottles and applied sequentially (Table 1 A shows the most common three-step adhesives available in the market). They are regarded as the gold standard due to their high durability and superior bonding strength, which can reach up to 51.39 MPa after a month of storage (Armstrong, Vargas et al., 2003, De Munck et al., 2005a).

Because of its organic composition, bonding to dentin is more challenging relative to the enamel. Moreover, during etching, there is a risk of dentin demineralization, which would expose the collagen fibrils or proteins (such as matrix metalloproteinases MMP 2,9,22) that facilitate the hybrid layer (enzymatic) degradation.

The two-step system—combining the primer with resin into one bottle, while using 35–37% phosphoric acid as an etching agent—is often used in clinical practice to minimize the number of bonding steps (the most common two-step adhesives are shown in Table 1 B). However, the bonding strength achieved by this system is weaker compared to the total-etch variants (40.36 MPa after a month of storage) and is prone to osmotic degradation, whereby the primer resin is converted from the hydrophobic to hydrophilic form (Armstrong et al., 2003).

Thus, to avoid the hybrid layer degradation and shorten the bonding steps, self-etching adhesive can be utilized (the most common types are shown in Table 1 C) (Sundfeld et al., 2005). This system is applied in one or two steps depending on the composition of the primer and the self-etch adhesive type. As acidic monomers are the main component of this adhesive, pH less than 1 is considered a strong acid, pH = 1.5 as intermediate, and pH > 2 as a mild acid. The main drawback of this system is the shallow hybrid layer and weak bonding (Kenshima et al. (2006)).

Lastly, universal adhesive systems, called "multi-mode" or "multi-purpose," represent the most common universal adhesives in the market (these are shown in Table 1 D). The system was introduced in 2011 and can be used as a self-etch on dentin and total-etch on enamel (Perdigão et al., 2012). The universal adhesive has a 10-methacryloyloxydecyl dihydrogen phosphate [MDP] that stimulates a solid adhesion to the tooth surface by forming a non-soluble Ca2 salt (Tay and Pashley, 2001). This system has Dipentaerythritol penta-acrylate phosphate ester and polyalkenoic acid, which are helpful in chemically bonding the resin (Tay and Pashley, 2001).

According to clinical and lab studies, total-etch adhesives, either 3-step or 2-step systems, have excellent bonding strength of CAD/CAM materials to the tooth structure (Mahn et al., 2015). On the other hand, self-etch systems showed unique features regarding the low incidence of postoperative sensitivity (Sancakli et al., 2014). Studies showed inferior clinical outcomes and weak bond strength, especially with all-in-one systems or self-etch adhesive, which mandates using phosphoric acid as a separate step to achieve reliable bonding to enamel (Peumans et al., 2014).

3.3. Bonding CAD/CAM materials on enamel vs dentin

Studies have shown different conclusions with respect to the longevity of the adhesive and CAD/CAM materials (Bavbek et al., 2013). The bonding strength of CAD/CAM materials might be distinctive due to the type of dental substrate since dental tissue has different compositions and volumes of minerals, protein, and water (Jain and Stewart, 2000). Enamel contains, by weight, 95% inorganic matter, 4% water, and 1% organic matter. Consider this compared to dentin, which has 65% inorganic matter, 20% water, and 15% organic matter (He and Swain, 2009). In vitro studies affirmed that bonding to enamel varies from bonding to dentin due to the chemical reaction in the presence or absence of moisture (Jang et al., 2016).

Enamel and dentin require different conditioning approaches; enamel surface must etch with 35% phosphoric acid for 20 s to remove the smear layer, providing 5 to 50 µm per space for bonding agents. Adhesion to dentin necessitates less time of etching (about 15 s) to provide space around 3.0 µm to 5.0 µm. Hydrophilic primer is the next step with ethanol, acetone, or a water base to facilitate the bifunctional interlocking between dentin and resin monomers (Perdigão et al., 1996).

Clinically, indirect restorations will bond onto both enamel and dentin, so selective etching is the ideal solution because it provides a high bonding quality for both structures (Cuevas-Suárez et al., 2019). Higher bonding strength to the enamel may be attained by one of these methods: using total-etch adhesives (Van Meerbeek et al., 2011) or "universal," "multi-purpose," or "multimode" adhesives combined with phosphoric acid as a separate step (Muñoz et al. (2013), Chen et al., 2015).

Bonding ceramic materials on dentin can be achieved with self-etching adhesives. Etching monomers can remove part of the smear layer and attach the resin to intrafibrillar dentin tubules. It can demineralize around 5 to 7 µm of dentin and increase the porosities within the collagen matrix (Pashley et al. (2011), Latta et al., 2020). The chemical reaction between carboxylic, phosphonic, or phosphate groups with mineral apatite increases resin permeability to dentin. However, increasing the etching time may lead to more dentinal fluid driven by pulpal pressure (Lin et al., 2010). Therefore, adhesion is more successful on superficial rather than deep dentin, which requires less tooth preparation and necessitates use of vasoconstrictor local anesthesia.

Dentinal tissue must seal immediately with a bonding agent to avoid bacterial leakage and post-operative sensitivity (Magne, 2005). This technique, called immediate dentin sealing, is usually done before the final impression to prevent any problems in restorations seating. The advantage is enhancing bond strength, (Jayasooriya et al., 2003a; Ozturk and Aykent, 2003) limiting the marginal gap, (Jayasooriya et al., 2003b) and reducing post-operative sensitivity.

3.4. Classification of CAD/CAM materials

CAD/CAM technology speeds the treatment in prosthodontics and advanced operative clinics. These technologies assist in scanning the prepped tooth, occlusion, and adjacent teeth using 3D designers, such as CEREC and Plan Scan systems. These systems need milling machines to fabricate restorations automatically (Alghazzawi, 2016; Kelly and Benetti, 2011; Kollmuss et al., 2016).

Ceramic materials are better than metal restorations due to their esthetic, optical properties, biocompatibility, and mechanical properties (Zarone et al., 2011). In the beginning, ceramic was fabricated from metallic and nonmetallic compounds. The microstructure then changed to be a silicon-based material. Today, ceramic is polycrystalline due to the hybridity in the compositions (Van Noort, 2007; Ho and Matinlinna, 2011).

Fig. 2 shows the Kelly and Benetti main classification for ceramic restorations. In general, ceramic is classified based on the phases present in its composition to predominantly

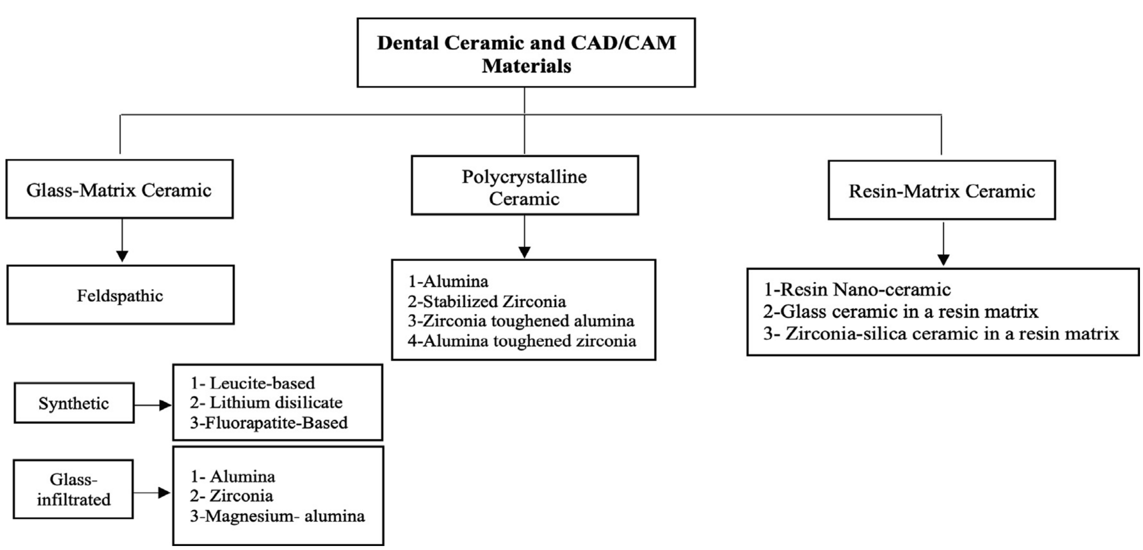

Fig. 2 Classification system of all –ceramic and ceramic like materials.

Table 2 Most of CAD/CAM Glass-Ceramics Materials.

Material	Brand name	Composition	Flexural strength
A			
Feldspathic ceramics	VITA Mark II	Mixtures of sodium potassium aluminum silicate peak [Na2O, Al2O3, 6SiO2] and [K2O, Al2O3, 6SiO2].	160 MPa (Bindl et al., 2003)
Leucite-reinforced glass-ceramics	Empress CAD	Leucite crystals up to 40% of [SiO2-Al2O3-K2O] and [Na2O, BaO, CaO, CeO2, B2O3, Ti02].	185 MPa (Höland et al., 2000)
Lithium disilicate–reinforced glass–ceramic	IPS e.max CAD	SiO_2-Li_2O-K_2O-ZnO-P_2O_5-Al_2O_3-ZrO_2 in needle-like shape [0.5 to 4 µm]. (Kokubo et al., 2009)	360 MPa (Guess et al., 2011)
Zirconia-reinforced lithium silicate	VITA Suprinity	10% by weight of dispersed zirconia particles embedded in a fine-grained glass matrix of 500 to 800 nm.Composed of [SiO2, Li2O, K2O, P2O5, Al2O3, ZnO2, CeO2]. (Cuevas-Suárez, da Rosa et al.)	380 MPa (VITA Suprinity: VITA Zahnfabrik, 2013)
	Celtra Duo	Containing 10% zirconia plus [SiO2, Li2O, Zr02, P2O5, Al2O3, K2O, CeO2]. Ultrafine lithium silicate crystals with an approximate size of 0.5 to 0.7 µm embedded in the glass matrix.	370 MPa (Celtra Duo. Dentsply, 2013)
B			
Alumina- based ceramics	ProceraTM AllCeram	High-purity Al_2O_3 around 99% combined with a low surface percaline.	600 MPa (Kokubo et al., 2009)
Zirconia-based Ceramics	NobelProcera Zirconia Nobel Biocare In-Ceram YZ Katana Zirconia	Zirconia {zirconium dioxide, ZrO2} combined with stabilizer as ceria [CeO2], yttria [Y2O3], alumina [Al2O3], magnesia [MgO] and calcia [CaO].	1000 MPa (Nistor et al., 2019)
C			
Hybrid ceramics	VITA Enamic	Glass-ceramic in a resin interpenetrating matrix.Ceramic: [86 wt%] composed of: SiO2, Al2O3, Na2O, K2O, and B2O3. Polymer: [14 wt%] composed of UDMA and TGDMA. (Coldea et al. (2013)	160 MPa (Wendler et al., 2017)
Resin nano-ceramics	Lava Ultimate	Nanometric colloidal silica clusters [0.6–10 µm] and ZrO2 spherical particles in agglomerated and non-agglomerated form [80% wt] embedded in polymer matrix [Bis-GMA + UDMA + Bis-EMA + TEG-DMA](Gracis et al., 2015; Gresnigt et al., 2016)	200 MPa (Lauvahutanon et al., 2014)
Nano-ceramic matrix	Cerasmart	Composite resin material with a flexible nanoceramic matrix and an even distribution of nanoceramic particles.	230 MPa (Lauvahutanon et al., 2014)

glass with inorganic material, polycrystalline contains inorganic ceramics without glass phase, and resin-matrix ceramics include polymer matrices with an inorganic component (Gracis et al., 2015).

3.4.1. Glass-Matrix ceramics

Table 2 A displays the most favorable glass-based that classified into three main categories: feldspathic, synthetic, and glass-infiltrated ceramics. The main structure has Quartz [55–65%] for the transparency, alumina [20–25%] for strength, plus kaolin [4%] opaquer. With the popularization of CAD/CAM technologies, glass-based ceramic ended up in different designs as lithium disilicate reinforced ceramics, leucite-reinforced glass-ceramics, glass infiltrated with alumina, and glass infiltrated with zirconia ceramics.

3.4.2. Polycrystalline ceramics

For CAD/CAM materials to be more substantial with high elastic modulus, they require agglomeration of fine-grain crystals without glass to prevent crack propagation. Table 2 B displays polycrystalline ceramic materials that are a good choice, especially for bruxism patients. This material has crystals densely packed into regular arrays and sintered with no glass matrix (Giordano, 2010). Alumina is an example of polycrystalline material made from powders filled with about 70% crystalline density. Typically, it shrinks approximately 30% by volume during firing, and the color will turn opaque (Kelly and Benetti, 2011).

Zirconia is now a well-known material in dentistry. It has widely spread over the past few years because of its outstanding physical properties and the high flexure strength that ranges from 900 to 1100 MPa (Papanagiotou et al., 2006). Zirconia mineral is extracted initially from zirconium and is crushed into a powder with specific particle size. Then, the zirconia powder is mixed with metal oxides, yttrium, aluminum, and hafnium. Each mineral serves a particular function; yttrium is used to stabilize the tetragonal phase and aluminum is used for corrosion resistance.

Zirconia has three temperature-dependent forms (Chevalier et al., 2009). The monoclinic phase is formed at a range from room temperature to 1170 °C, the tetragonal phase is formed in temperatures ranging between 1170 °C and 2370 °C, and the cubic phase is formed from 2370 °C to the melting point (Liu and Essig, 2008; Miyazaki et al., 2013). When zirconia presents in the monoclinic phase, the final material will be weak. Therefore, enhancement of strength and fracture toughness occurs while the powder is first processing to stabilize the tetragonal phase at room temperature. Still, this process is accompanied by a volume shrinkage of around 4% to 5%.

Table 3 Summary of Surface conditioning protocol for CAD/CAM materials.

Restoration preparation	Exact methods
A	Conditioning Protocol for Glassy Matrix Ceramics
Cleaning a restoration before try-in	- Restoration is cleaned with ultrasonic technique in a water bath. - Restoration dries to avoid any bacteria transmission to a patient.
Cleaning intaglio surface of CAD/CAM materials after try-in.	- Two ways of cleaning:1- Sandblasting with alumina oxide 50-µm, then rinsing and drying.2- Ultrasonic cleaning in distilled water for 5 min.3- Using a layer of Ivoclean by applying it to the entire bonding surface of the restoration for 20 s, then rinsing and drying. (Information provided by Ivoclar Vivadent Inc, 2013)
Etching the intaglio surface with hydrofluoric acid.	1-Placing the acid liquid inside or on the face of the surface.2- For feldspathic ceramic: 9.6% HF for 2 min.3- For leucite reinforced ceramics: 5% HF for 1 min.4- For lithium-disilicate–reinforced ceramics: 5% HF for 20 s. (Matinlinna and Vallittu, 2007)
Washing and rinsing the etched ceramic surface	Tap water rinsing for at least 1 min.
Appling Phosphoric Acid H3PO4	Placing the etching acid with continuous agitation for 10 s.
Appling a silane coupling agent	1-Using a clean brush, and dry for a minute
B	Conditioning Protocol for Polymer-infiltrated Restorations
Cleaning a restoration before try-in	- Restoration is cleaned with ultrasonic technique in a water bath. - Restoration dries to avoid any bacteria transmission to a patient.
Cleaning intaglio surface of CAD/CAM materials after try-in.	- Two ways of cleaning: 1- Sandblasting with alumina oxide 50-µm. 2- Ultrasonic cleaning in distilled water for 5 min.
Etching the intaglio surface with hydrofluoric acid.	- 2–5% hydrofluoric acid for 60 s.
Washing and rinsing the etched ceramic surface	- Tap water rinsing for at least 1 min or scrub phosphoric acid with a clean brush for 20 s.
Appling Phosphoric Acid H_3PO_4	- Placing the etching acid with continuous agitation for 10 s, and that helps to remove the hazardous HF remnants.
Appling a silane coupling agent	- Using a clean brush, and dry for a minute.
C	Conditioning Protocol for Zirconia Restorations (Inokoshi and Van Meerbeek, 2014)
Cleaning a restoration before try-in	- Restoration is cleaned with ultrasonic in a water bath - Restoration dry to avoid any bacteria transmission to a patient.
Sandblasting intaglio with silica coated Al_2O_3 particles 50 µm in size.	- Using low pressure [1–2 bar] to avoid large cracks.
Cleaning the intaglio surface.	- Using a cleaning paste [Ivoclean] for 20 s. (Alfaro et al., 2016)- Rinse and dry with oil free line.
Apply a combined 10-MD, silane ceramic primer.	- Using a clean brush and dry for a minute.
D	Conditioning Protocol Nanoceramic Restorations
Sandblasting the material surface with silica coated Al_2O_3 particles or air abrasion with 27 to 50 µm in size.	- Using low pressure [1–2 bar] to avoid large cracks.
Cleaning intaglio surface of CAD/CAM materials after try-in.	- Ultrasonic cleaning in distilled water for 5 min or using phosphoric acid for 20 s.
Apply a universal adhesive agent	- Using a clean micro brush for 20 s, and dry for 5 s without light curing (Fuentes et al., 2013).

However, this phase is changeable and not stable under extreme stresses as bur grinding that known as t → m transformations (Zhang and Lawn, 2018).

3.4.3. Resin-Matrix ceramics

Resin-matrix ceramics are classified as ceramic materials containing 50% of inorganic structures and few organic polymers (American Dental Association. CDT: Code on dental procedures and nomenclature. http://www.ada.org/en/publications/cdt/. Accessed March 17). Table 2 C illustrations the different types of Resin-matrix CAD/CAM materials that signify the advantages of polymers and glass-ceramics (Coldea et al., 2013). Resin-matrix ceramics have a high modulus of elasticity, similar to dentin tissue. Furthermore, they do not require any further steps after milling, and they are easy to repair and modify with a direct composite material. Regarding material longevity, most clinical trials showed acceptable clinical results, with a survival rate of 90% after 5 years.

They used 3-D design.

3.5. Surface conditioning protocol for CAD/CAM materials

CAD/CAM materials require an ideal intaglio treatment before bonding to the tooth structure. To ensure the proper surface conditions, a complete understanding of the ceramic microstructure is necessary (M. N. Aboushelib and Sleem, 214). CAD/CAM materials can be treated chemically or mechanically (Blatz et al., 2003; Strasser et al., 2018). The chemical treatment is usually done with 5% or 9 % hydrofluoric acid (Tian et al., 2014). The acid reacts with silica to form hydrofluorosilicic acid, creating a space for resin cement and making the surface rougher (Alex, 2008). Monobond silane coupling agent is used after the acid to enhance the chemical adhesion to CAD/CAM materials. It combines silane, phosphoric, and sulfide methacrylate.

The mechanical treatment is done by subjecting the intaglio surface to air particles abrasion with 25, 27, or 50-μm aluminum oxide. Sandblasting with alumina air particles showed a significant surface alteration in hybrid ceramic resin and zirconia restorations (M. N. Aboushelib and Sleem, 214).

3.5.1. Adhesion to glass matrix restorations

Feldspathic, leucite, and lithium disilicate materials require ideal surface conditioning using hydrofluoric acid gel or a phosphate fluoride, as shown in Table 3 A. The acid purpose is to remove part of the silica from a matrix, exposing the glass to increase the adhesion of resin-based luting cement to the intaglio surface (Özcan and Volpato, 2015). On the other side, silane coupling agents encourage adhesion by forming the siloxane bonds between the inorganic materials of the ceramic and the organic materials of the bonding agent (Matinlinna et al., 2006).

3.5.2. Adhesion to polymer-infiltrated ceramic

This material was announced when CAD/ CAM technologies began using it significantly in dentistry. The microstructure of this material contains a ceramic matrix filled with less polymer material. The intaglio surface is treated with etching gel to provide an optimum interface with resin cement, as shown in Table 3 B. Etching will expose the resin network and selectively remove part of the ceramic matrix (Hu et al., 2016). Salination is an important step; methoxy groups in silane will react chemically with SiO2 and polymer resin, which forms the chemical adhesion (Elsaka, 2015).

3.5.3. Adhesion to Zirconia restorations

Zirconia is one of the most-used restorative material as the accessibility of CAD/ CAM technologies grows. Bonding zirconia is beneficial because it supports a thin or less durable restoration; it demands proper surface treatment for the restoration and the tooth, as shown in Table 3 C (Blatz et al., 2010). Zirconia material cannot be roughened with etching gel because of the lack of silica, so the bonding is achieved by applying the APC concept. This concept involves three practical steps: air particle abrasion, zirconia primer, and adhesive resin (Blatz et al., 2016).

3.5.4. Adhesion to nanoceramic indirect restorations

The new hybrid Lava Ultimate materials have advantages over composite materials. They have a nice glossy surface, accepted compressive strength, and excellent machinability and repairability. The surface treatment of this material is different, as shown in Table 3 D. It contains 80 wt% of zirconia and silica particle entrenched in a 20 wt% resin matrix (Fasbinder, 2012). The intaglio surface is treated by air abrasion of 27 μm aluminum oxide at a pressure of 2 bar (Özcan and Volpato, 2016). Sandblasting the material will enhance the roughness and provide micromechanical and chemical adhesion of the adhesive resin cement (Blatz et al., 2003).

3.6. Adhesive resin cements for CAD/CAM restorations

Resin cement can be categorized based on chemical interaction with the dental tissue into three types: non-adhesive, chemically bonded, and micromechanical bonded cement (Sillas Duarte Jr, 2011). Non-adhesive cement does not require surface treatment for either a tooth or a restoration. It is commonly used with porcelain fused to metal or thicker ceramic restorations (1.5 mm to 2 mm).

Table 4 A shows the most common etching and rinsing adhesive cements that have the same clinical steps as the total-etch adhesive system. The tooth surface is usually etched with 35% phosphoric acid for conditioning the surface to create some roughness, which helps cement infiltrate deeper inside the porosities (Thompson et al., 2011).

Table 4 B displays the self-etch adhesive cement that eliminates the usage of acid etching. In this case, no rinsing is required, and an acidic monomer will saturate the smear layer (Tay et al., 2000). Self-etch adhesives have varying acidic pH—ultra-mild (pH $>$ 2.5), mild (pH $\approx$ 2.0), and strong (pH $\leq$ 1.0)—and have 10 MDP that interact chemically with tooth structure to enhance the bonding durability (Van Meerbeek et al., 2011).

Self-adhesive resin cement has been introduced as a substitute for multistep resin cement. It does not require any surface conditioning. Moreover, phosphoric acid methacrylate (with a pH less than 2.0) can partially remove tooth minerals and replace them with cement (De Munck et al., 2004; Goracci et al., 2006). The bonding strength will be less than other types of adhesive cements due to the accumulation of the smear plug in the interface (Al-Assaf et al., 2007).

In terms of comparability, zinc phosphate cement and glass ionomer cement produce the lowest shear bond strengths. The highest shear bond strengths were found with Panavia F2.0, Multilink, and Rely X Unicem (Peutzfeldt et al., 2011). Self-etch cement presents a better bonding strength than self-adhesive cement, especially on dentin substrate. A self-etching cement, either dual-cure, light-cure, or flow, produce better results, such as Variolink II or Excite DSC, to the enamel. Moreover, Variolink II and Panavia show higher bonding strength when restoration adheres to dentin and enamel (Lührs et al., 2010).

Table 4 summary of *Adhesive resin cements for CAD/CAM restorations.*

Resin cement	Polymerization mode	Adhesive system uses with it
A	Etch and rinse adhesive cement	
Variolink II	Dual-cured	Excite F DSC
Rely X ARC	Dual-cured	Adper Single Bond Plus
Variolink Veneer	Light-cured	Excite F
Rely X Veneer Cement	Light-cured	Adper Single Bond Plus
B	Self-etch adhesive cement	
Clearfil Esthetic Cement	Dual-cured	OptiBond XTR
Panavia 21	Self-cured	Clearfil DC Bond
Panavia F 2.0	Dual-cured	ED primer II

4. Discussion

This review is designed to create up-to-date scientific guidelines regarding adhesion protocols for CAD / CAM material to the tooth structure, clarifying the various types of adhesive systems. This paper aims to provide a recent overview that explains each topic separately and then compares the differences between adhesive systems, CAD/CAM materials, and resin cement in an orderly fashion.

This topic appeals to many practitioners because of the widespread use of ceramic and adhesive materials. Furthermore, old retention concepts, like pins and grooves, have been substituted with chemical and micromechanical adhesion to save tooth structures from aggressive preparation. Ceramic and zirconia restorations showed more advantages than metal or gold restorations due to the manufacturing simplicity with CAD/CAM technology.

In the past, CAD/CAM materials were cemented with conventional cement-like glass ionomers with limited adhesive technique, so thicker ceramic materials were required to withstand the masticatory forces, which necessitated a harsh preparation for tooth structure.

The results of many studies approved the necessity of close attention to the adhesive system, dental substrate, resin cement, and types of ceramic restorations, which can help in saving tooth structure with high bonding strength, as shown in Blatz et al. (Blatz et al., 2018) Moreover, developments in adhesive dentistry have increased the spread of ceramic materials, from glass-based to polycrystalline to resin-matrix ceramics.

The dental substrate is fundamental to bonding success because bonding to dentin is more challenging than enamel, as demonstrated in Henrique et al. (Susin et al. (2007)) Enamel is a solid structure and contains less water, which leads to a successful bonding for the CAD/CAM restorations (De Munck et al., 2005a; Souza-Zaroni et al., 2007).

Immediate dentin sealing (IDS) is a procedure in which a resin layer is applied immediately after tooth preparation to enhance the bonding strength and decrease gap formations, bacterial leakage, and sensitivity, as shown in shown in Magne et al. (Magne, 2005).

Restorative dentistry has shifted from conservative to ultra-conservative approach, which demands adhesive systems that improve the adherence of the ceramic and resin materials to the tooth structure, as shown in the paper by Monck et al. (De Munck et al., 2005b).

Today, many companies still manufacture various systems to simplify the clinical steps by achieving a high bonding strength. However, choosing among them is still confusing and requires a lot of experience.

Bonding CAD/CAM restorations to tooth structure require a surface conditioner for intaglio by sandblaster or hydrofluoric acid, followed by monobond salinization (Guimarães et al., 2018). zirconia needs another treatment by applying the APC technique (Blatz et al., 2016).

Many CAD/CAM blocks are available, and the intent of finding them is to facilitate the construction of all types of restorations (Lambert et al., 2017). However, none of these materials are perfect for all cases, and their selection depends on the strength, aesthetics, accuracy, and reliable bonding to dental substrates.

Several in vitro studies revealed differences in the bonding strength of restorative materials. Hence, the materials, adhesion protocol, and adhesive system will lead to different results. The reason is the complexity of the technique that relies upon the experience and abilities of the operator.

5. Conclusion

Bonding to tooth structure relies on adhesive materials and their reaction with the dental substrate. The adhesion to ceramic materials is promoted by creating a micro-retentive surface using the sandblaster or HF etching, followed by a monobond primer to enhance the chemical bonding. A three-step adhesive system is the most effective way to lower the risk of hydrolytic degradation at the interface. It is preferred for indirect restorations and when the enamel is still present. The self-etched adhesive systems become simplified with minimal steps and are recommended when most of the substrate is dentin. The long-term clinical success of CAD/CAM materials is well proven; once the material is appropriately bonded, using ideal adhesive and resin cement.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

Especial thanks to Dr. John L. Ricci for his supervision and permission to use New York University resources.

References

Al-Assaf, K., Chakmakchi, M., Palaghias, G., Karanika-Kouma, A., Eliades, G., 2007. Interfacial characteristics of adhesive luting resins and composites with dentine. Dent. Mater. 23 (7), 829–839.

Alex, G., 2008. Preparing porcelain surfaces for optimal bonding. Compend. Contin. Educ. Dent. 29 (6). 324-335; quiz 336.

Alfaro, M.J., Meyers, E.J., Ashcraft-Olmscheid, D., Vandewalle, K.S., 2016. Effect of a new salivary-contaminant removal method on bond strength. Gen. Dent. 64 (3), 51–54.

Alghazzawi, T.F., 2016. Advancements in CAD/CAM technology: Options for practical implementation. J. Prosthodont. Res. 60 (2), 72–84.

American Dental Association. CDT: Code on dental procedures and nomenclature. http://www.ada.org/en/publications/cdt/. Accessed March 17.

Angeletaki, F., Gkogkos, A., Papazoglou, E., Kloukos, D., 2016. Direct versus indirect inlay/onlay composite restorations in posterior teeth. A systematic review and meta-analysis. J. Dent. 53, 12–21.

Armstrong, S.R., Vargas, M.A., Fang, Q., Laffoon, J.E., 2003. Microtensile bond strength of a total-etch 3-step, total-etch 2-step, self-etch 2-step, and a self-etch 1-step dentin bonding system through 15-month water storage. J. Adhes. Dent. 5 (1), 47–56.

Arnetzl, G., Arnetzl, G.V., 2015. Hybrid materials offer new perspectives. Int. J. Comput. Dent. 18 (2), 177–186.

Bavbek, A.B., Goktas, B., Cekic-Nagas, I., Egilmez, F., Ergun, G., Eskitascioglu, G., 2013. Micro-shear bond strength of resin cement to dentin after application of desensitizing toothpastes. Acta Odontol. Scand. 71 (3–4), 952–956.

Bedran-Russo, A., Leme-Kraus, A.A., Vidal, C.M.P., Teixeira, E.C., 2017. An Overview of Dental Adhesive Systems and the Dynamic Tooth-Adhesive Interface. Dent. Clin. North Am. 61 (4), 713–731.

Bindl, A., Lüthy, H., Mörmann, W.H., 2003. Fracture load of CAD/CAM-generated slot-inlay FPDs. Int. J. Prosthodont. 16 (6), 653–660.

Blatz, M.B., Alvarez, M., Sawyer, K., Brindis, M., 2016. How to Bond Zirconia: The APC Concept. Compend. Contin. Educ. Dent. 37 (9), 611–617. quiz 618.

Blatz, M.B., Phark, J.H., Ozer, F., Mante, F.K., Saleh, N., Bergler, M., Sadan, A., 2010. In vitro comparative bond strength of contemporary self-adhesive resin cements to zirconium oxide ceramic with and without air-particle abrasion. Clin. Oral Investig. 14 (2), 187–192.

Blatz, M.B., Sadan, A., Kern, M., 2003. Resin-ceramic bonding: a review of the literature. J. Prosthet. Dent. 89 (3), 268–274.

Blatz, M.B., Vonderheide, M., Conejo, J., 2018. The Effect of Resin Bonding on Long-Term Success of High-Strength Ceramics. J. Dent. Res. 97 (2), 132–139.

Celtra Duo. Dentsply, 2013.

Chen, C., Niu, L.N., Xie, H., Zhang, Z.Y., Zhou, L.Q., Jiao, K., Chen, J.H., Pashley, D.H., Tay, F.R., 2015. Bonding of universal adhesives to dentine–Old wine in new bottles? J. Dent. 43 (5), 525–536.

Chevalier, J., Gremillard, L., Virkar, A.V., Clarke, D.R., 2009. The tetragonal- monoclinic transformation in zirconia: Lessons learned and future trends. J. Am. Ceram. Soc. 92, 1901–1920.

Coldea, A., Swain, M.V., Thiel, N., 2013. Mechanical properties of polymer-infiltrated-ceramic-network materials. Dent. Mater. 29 (4), 419–426.

Cuevas-Suárez, C.E., da Rosa, W.L.O., Lund, R.G., da Silva, A.F., Piva, E., 2019. Bonding Performance of Universal Adhesives: An Updated Systematic Review and Meta-Analysis. J. Adhes. Dent. 21 (1), 7–26.

De Munck, J., Van Landuyt, K., Peumans, M., Poitevin, A., Lambrechts, P., Braem, M., Van Meerbeek, B., 2005a. A critical review of the durability of adhesion to tooth tissue: methods and results. J. Dent. Res. 84 (2), 118–132.

De Munck, J., Vargas, M., Iracki, J., Van Landuyt, K., Poitevin, A., Lambrechts, P., Van Meerbeek, B., 2005b. One-day bonding effectiveness of new self-etch adhesives to bur-cut enamel and dentin. Oper. Dent. 30 (1), 39–49.

De Munck, J., Vargas, M., Van Landuyt, K., Hikita, K., Lambrechts, P., Van Meerbeek, B., 2004. Bonding of an auto-adhesive luting material to enamel and dentin. Dent. Mater. 20 (10), 963–971.

Elsaka, S.E., 2014. Bond strength of novel CAD/CAM restorative materials to self-adhesive resin cement: the effect of surface treatments. J. Adhes. Dent. 16 (6), 531–540.

Elsaka, S.E., 2015. Repair bond strength of resin composite to a novel CAD/CAM hybrid ceramic using different repair systems. Dent. Mater. J. 34 (2), 161–167.

Fasbinder, D.J., 2012. Chairside CAD/CAM: an overview of restorative material options. Compend. Contin. Educ. Dent. 33 (1), 52–58. 50.

Fuentes, M.V., Ceballos, L., Gonzalez-Lopez, S., 2013. Bond strength of self-adhesive resin cements to different treated indirect composites. Clin. Oral Investig. 17 (3), 717–724.

Giordano, R.M.E., 2010. Ceramic overview: classification by microstructure and processing methods. Compend. Contin. Educ. Dent. 31, 682–688.

Goracci, C., Cury, A.H., Cantoro, A., Papacchini, F., Tay, F.R., Ferrari, M., 2006. Microtensile bond strength and interfacial properties of self-etching and self-adhesive resin cements used to lute composite onlays under different seating forces. J. Adhes. Dent. 8 (5), 327–335.

Gracis, S., Thompson, V.P., Ferencz, J.L., Silva, N.R., Bonfante, E.A., 2015. A new classification system for all-ceramic and ceramic-like restorative materials. Int. J. Prosthodont. 28 (3), 227–235.

Gresnigt, M.M., Özcan, M., van den Houten, M.L., Schipper, L., Cune, M.S., 2016. Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. Dent. Mater. 32 (5), 607–614.

Guess, P.C., Schultheis, S., Bonfante, E.A., Coelho, P.G., Ferencz, J. L., Silva, N.R., 2011. All-ceramic systems: laboratory and clinical performance. Dent. Clin. North Am. 55 (2), 333–352. ix.

Guimarães, H.A.B., Cardoso, P.C., Decurcio, R.A., Monteiro, L.J.E., de Almeida, L.N., Martins, W.F., Magalhães, A.P.R., 2018. Simplified Surface Treatments for Ceramic Cementation: Use of Universal Adhesive and Self-Etching Ceramic Primer. Int. J. Biomater. 2018, 2598073.

He, L.-H., Swain, M.V., 2009. Enamel—A functionally graded natural coating. J. Dent. 37 (8), 596–603.

Ho, G.W., Matinlinna, J.P., 2011. Insights on Ceramics as Dental Materials. Part I: Ceramic Material Types in Dentistry. Silicon 3 (3), 109–115.

Höland, W., Schweiger, M., Frank, M., Rheinberger, V., 2000. A comparison of the microstructure and properties of the IPS Empress 2 and the IPS Empress glass-ceramics. J. Biomed. Mater. Res. 53 (4), 297–303.

Hu, M., Weiger, R., Fischer, J., 2016. Comparison of two test designs for evaluating the shear bond strength of resin composite cements. Dent. Mater. 32 (2), 223–232.

Information provided by Ivoclar Vivadent Inc, H. t. p. c. r. a. t.-i., February 08, 2013.

Inokoshi, M., Van Meerbeek, B., 2014. Adhesively luted zirconia restorations: why and how? J. Adhes. Dent. 16 (3), 294.

Jain, P., Stewart, G.P., 2000. Effect of dentin primer on shear bond strength of composite resin to moist and dry enamel. Oper. Dent. 25 (1), 51–58.

Jang, J.H., Lee, M.G., Woo, S.U., Lee, C.O., Yi, J.K., Kim, D.S., 2016. Comparative study of the dentin bond strength of a new universal adhesive. Dent. Mater. J. 35 (4), 606–612.

Jayasooriya, P.R., Pereira, P.N., Nikaido, T., Tagami, J., 2003a. Efficacy of a resin coating on bond strengths of resin cement to dentin. J. Esthet. Restor. Dent. 15 (2), 105–113. discussion 113.

Jayasooriya, P.R., Pereira, P.N., Nikaido, T., Burrow, M.F., Tagami, J., 2003b. The effect of a "resin coating" on the interfacial adaptation of composite inlays. Oper Dent. 28, 28–35.

Kelly, J.R., Benetti, P., 2011. Ceramic materials in dentistry: historical evolution and current practice. Aust. Dent. J. 56 (Suppl 1), 84–96.

Kenshima, S., Francci, C., Reis, A., Loguercio, A.D., Filho, L.E.R., 2006. Conditioning effect on dentin, resin tags and hybrid layer of different acidity self-etch adhesives applied to thick and thin smear layer. J. Dent. 34 (10), 775–783.

Kokubo, Y., Sakurai, S., Tsumita, M., Ogawa, T., Fukushima, S., 2009. Clinical evaluation of Procera AllCeram crowns in Japanese patients: results after 5 years. J. Oral Rehabil. 36 (11), 786–791.

Kollmuss, M., Kist, S., Goeke, J.E., Hickel, R., Huth, K.C., 2016. Comparison of chairside and laboratory CAD/CAM to conventional produced all-ceramic crowns regarding morphology, occlusion, and aesthetics. Clin. Oral Investig. 20 (4), 791–797.

Lambert, H., Durand, J.C., Jacquot, B., Fages, M., 2017. Dental biomaterials for chairside CAD/CAM: State of the art. J. Adv. Prosthodont. 9 (6), 486–495.

Landis, J.R., Koch, G.G., 1977. The measurement of observer agreement for categorical data. Biometrics 33 (1), 159–174.

Latta, M.A., Tsujimoto, A., Takamizawa, T., Barkmeier, W.W., 2020. Enamel and Dentin Bond Durability of Self-Adhesive Restorative Materials. J. Adhes. Dent. 22 (1), 99–105.

Lauvahutanon, S., Takahashi, H., Shiozawa, M., Iwasaki, N., Asakawa, Y., Oki, M., Finger, W.J., Arksornnukit, M., 2014.

Mechanical properties of composite resin blocks for CAD/CAM. Dent. Mater. J. 33 (5), 705–710.
Lin, J., Mehl, C., Yang, B., Kern, M., 2010. Durability of four composite resin cements bonded to dentin under simulated pulpal pressure. Dent. Mater. 26 (10), 1001–1009.
Liu, P.R., Essig, M.E., 2008. Panorama of dental CAD/CAM restorative systems. Compend. Contin. Educ. Dent. 29 (8). 482, 484, 486-488 passim.
Lührs, A.K., Guhr, S., Günay, H., Geurtsen, W., 2010. Shear bond strength of self-adhesive resins compared to resin cements with etch and rinse adhesives to enamel and dentin in vitro. Clin. Oral Investig. 14 (2), 193–199.
M. N. Aboushelib, D. Sleem, 2014. M. b. s. o. l. d. c. t. r. a., J. Adhesive Dentistry, 16(6), 547–552.
Magne, P., 2005. Immediate dentin sealing: a fundamental procedure for indirect bonded restorations. J. Esthet. Restor. Dent. 17 (3), 144–154. discussion 155.
Mahn, E., Rousson, V., Heintze, S., 2015. Meta-Analysis of the Influence of Bonding Parameters on the Clinical Outcome of Tooth-colored Cervical Restorations. J. Adhes. Dent. 17 (5), 391–403.
Matinlinna, J.P., Heikkinen, T., Ozcan, M., Lassila, L.V., Vallittu, P. K., 2006. Evaluation of resin adhesion to zirconia ceramic using some organosilanes. Dent. Mater. 22 (9), 824–831.
Matinlinna, J.P., Vallittu, P.K., 2007. Bonding of resin composites to etchable ceramic surfaces - an insight review of the chemical aspects on surface conditioning. J. Oral Rehabil. 34 (8), 622–630.
Miyazaki, T., Nakamura, T., Matsumura, H., Ban, S., Kobayashi, T., 2013. Current status of zirconia restoration. J Prosthodont Res 57 (4), 236–261.
Muñoz, M.A., Luque, I., Hass, V., Reis, A., Loguercio, A.D., Bombarda, N.H., 2013. Immediate bonding properties of universal adhesives to dentine. J. Dent. 41 (5), 404–411.
Neimar Sartori (2017). "The Adhesive Restorative Complex (ARC) Concept." QDT.
Nistor, L., Grădinaru, M., Rîcă, R., Mărăşescu, P., Stan, M., Manolea, H., Ionescu, A., Moraru, I., 2019. Zirconia Use in Dentistry - Manufacturing and Properties. Current Health Sci. J. 45 (1), 28–35.
Özcan, M., Volpato, C., 2016. Surface Conditioning and Bonding Protocol for Nanocomposite Indirect Restorations: How and Why? J. Adhes. Dent 18 (1), 82.
Özcan, M., Volpato, C.A., 2015. Surface Conditioning Protocol for the Adhesion of Resin-based Materials to Glassy Matrix Ceramics: How to Condition and Why? J. Adhes. Dent. 17 (3), 292–293.
Ozturk, N., Aykent, F., 2003. Dentin bond strengths of two ceramic inlay systems after cementation with three different techniques and one bonding system. J. Prosthet. Dent. 89 (3), 275–281.
Papanagiotou, H.P., Morgano, S.M., Giordano, R.A., Pober, R., 2006. In vitro evaluation of low-temperature aging effects and finishing procedures on the flexural strength and structural stability of Y-TZP dental ceramics. J. Prosthet. Dent. 96 (3), 154–164.
Pashley, D.H., Tay, F.R., Breschi, L., Tjäderhane, L., Carvalho, R.M., Carrilho, M., Tezvergil-Mutluay, A., 2011. State of the art etch-and-rinse adhesives. Dental Mater. : Off. Publ. Acad. Dental Mater. 27 (1), 1–16.
Perdigao, J., 2007. New developments in dental adhesion. Dent. Clin. North Am. 51 (2), 333–357. viii.
Perdigão, J., Lambrechts, P., Van Meerbeek, B., Braem, M., Yildiz, E., Yücel, T., Vanherle, G., 1996. The interaction of adhesive systems with human dentin. Am. J. Dent. 9 (4), 167–173.
Perdigão, J., Sezinando, A., Monteiro, P.C., 2012. Laboratory bonding ability of a multi-purpose dentin adhesive. Am. J. Dent. 25 (3), 153–158.
Peumans, M., De Munck, J., Mine, A., Van Meerbeek, B., 2014. Clinical effectiveness of contemporary adhesives for the restoration of non-carious cervical lesions. A systematic review. Dent. Mater. 30 (10), 1089–1103.
Peumans, M., De Munck, J., Van Landuyt, K.L., Poitevin, A., Lambrechts, P., Van Meerbeek, B., 2010. Eight-year clinical evaluation of a 2-step self-etch adhesive with and without selective enamel etching. Dent. Mater. 26 (12), 1176–1184.
Peutzfeldt, A., Sahafi, A., Flury, S., 2011. Bonding of Restorative Materials to Dentin With Various Luting Agents. Operative Dentistry 36 (3), 266–273.
Piwowarczyk, A., Lauer, H.C., Sorensen, J.A., 2004. In vitro shear bond strength of cementing agents to fixed prosthodontic restorative materials. J. Prosthet. Dent. 92 (3), 265–273.
Ruse, N.D., Sadoun, M.J., 2014. Resin-composite blocks for dental CAD/CAM applications. J. Dent. Res. 93 (12), 1232–1234.
Sancakli, H.S., Yildiz, E., Bayrak, I., Ozel, S., 2014. Effect of different adhesive strategies on the post-operative sensitivity of class I composite restorations. Eur. J. Dent. 8 (1), 15–22.
Sillas Duarte Jr, N. S., 2011. Adhesive Resin Cements for Bonding Esthetic Restorations: A Review. QDT.
Sofan, E., Sofan, A., Palaia, G., Tenore, G., Romeo, U., Migliau, G., 2017. Classification review of dental adhesive systems: from the IV generation to the universal type. Annali di stomatologia 8 (1), 1–17.
Souza-Zaroni, W.C., Seixas, L.C., Ciccone-Nogueira, J.C., Chimello, D.T., Palma-Dibb, R.G., 2007. Tensile bond strength of different adhesive systems to enamel and dentin. Brazilian Dental J. 18, 124–128.
Strasser, T., Preis, V., Behr, M., Rosentritt, M., 2018. Roughness, surface energy, and superficial damages of CAD/CAM materials after surface treatment. Clin. Oral Investig. 22 (8), 2787–2797.
Sundfeld, R.H., Valentino, T.A., de Alexandre, R.S., Briso, A.L., Sundefeld, M.L., 2005. Hybrid layer thickness and resin tag length of a self-etching adhesive bonded to sound dentin. J. Dent. 33 (8), 675–681.
Susin, A.H., Vasconcellos, W.A., Saad, J.R., Oliveira Junior, O.B., 2007. Tensile bond strength of self-etching versus total-etching adhesive systems under different dentinal substrate conditions. Braz. Oral. Res. 21 (1), 81–86.
Tay, F.R., Carvalho, R., Sano, H., Pashley, D.H., 2000. Effect of smear layers on the bonding of a self-etching primer to dentin. J. Adhes. Dent. 2 (2), 99–116.
Tay, F.R., Pashley, D.H., 2001. Aggressiveness of contemporary self-etching systems. I: Depth of penetration beyond dentin smear layers. Dent. Mater. 17 (4), 296–308.
Thompson, J.Y., Stoner, B.R., Piascik, J.R., Smith, R., 2011. Adhesion/cementation to zirconia and other non-silicate ceramics: where are we now? Dent. Mater. 27 (1), 71–82.
Tian, T., Tsoi, J.-K.-H., Matinlinna, J.P., Burrow, M.F., 2014. Aspects of bonding between resin luting cements and glass ceramic materials. Dent. Mater. 30 (7), e147–e162.
Van Landuyt, K.L., Snauwaert, J., De Munck, J., Peumans, M., Yoshida, Y., Poitevin, A., Coutinho, E., Suzuki, K., Lambrechts, P., Van Meerbeek, B., 2007. Systematic review of the chemical composition of contemporary dental adhesives. Biomaterials 28 (26), 3757–3785.
Van Meerbeek, B., Yoshihara, K., Yoshida, Y., Mine, A., De Munck, J., Van Landuyt, K.L., 2011. State of the art of self-etch adhesives. Dent. Mater. 27 (1), 17–28.
Van Noort, R., 2007. Introduction to dental materials. 3rd ed. Elsevier, P.
VITA Suprinity: VITA Zahnfabrik, 2013. Technical and Scientific Documentation.
Wendler, M., Belli, R., Petschelt, A., Mevec, D., Harrer, W., Lube, T., Danzer, R., Lohbauer, U., 2017. Chairside CAD/CAM materials. Part 2: Flexural strength testing. Dent. Mater. 33 (1), 99–109.
Zarone, F., Russo, S., Sorrentino, R., 2011. From porcelain-fused-to-metal to zirconia: clinical and experimental considerations. Dent. Mater. 27 (1), 83–96.
Zhang, Y., Lawn, B.R., 2018. Novel Zirconia Materials in Dentistry. J. Dent. Res. 97 (2), 140–147.