EGAS MONIZ SCHOOL of HEALTH & SCIENCE | INSTITUTO UNIVERSITÁRIO EGAS MONIZ

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MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

BONDING PROTOCOL FOR INDIRECT CERAMIC RESTORATIONS IN POSTERIOR TEETH: RECOMMENDATIONS FOR SUCCESS

Trabalho submetido por
MAYSSA JBENIANY
para a obtenção do grau de Mestre em Medicina Dentária

julho de 2024

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ABSTRACT

Advancements in dentistry through the development of bonding systems, the appearance of new ceramics and innovations in manufacturing processes have significantly changed classical dentistry paradigm.

This transformation has given rise to modern dentistry guided by gradient therapeutic concepts and the respect of the tissue economy.

In this context, bonded indirect restorations for posterior teeth have emerged as a reliable and durable therapeutic solution.

In this work, we will attempt to clarify and explain the different types of ceramics and their indications. Secondly, we will describe the different types of indirect ceramic restorations and update our knowledge of their indications and preparation principles. In the final section, we describe the bonding protocol and the new materials with recommendations for optimizing and facilitating understanding of these restorations.

The present work consists of a bibliographic review on the bonding of indirect restorations for posterior teeth, focusing essentially on the new approaches regarding new ceramics, preparation, and adhesion techniques.

The literature review was carried out by searching articles in the databases Pubmed, Web of Science and Cochrane with the following keywords: (bonding) OR (mini-invasive restorations) OR (ceramics) AND (preparations of posterior teeth). Articles in English, French and Portuguese published over the past 15 years were included.

Key-words: bonding, ceramics, indirect restorations, posterior teeth.

RESUMO

Os avanços na área da Medicina Dentária, resultantes do desenvolvimento de novos sistemas adesivos, do surgimento de novas cerâmicas e de inovações nos processos de fabricação, provocaram uma mudança significativa na reabilitação oral minimamente invasiva.

Essa transformação deu origem à medicina dentária moderna, que se guia por conceitos terapêuticos progressivos e pela importância da preservação dos tecidos .

Nesse contexto, as restaurações indiretas adesivas para dentes posteriores emergiram como uma solução terapêutica confiável e duradoura .

Neste trabalho, buscamos esclarecer e explicar os diversos tipos de cerâmicas e suas aplicações. Em seguida, descreveremos os diferentes tipos de restaurações cerâmicas indiretas e atualizaremos o nosso conhecimento sobre as suas aplicações e princípios de preparação. Na secção final, detalharemos o protocolo de adesão e os novos materiais, oferecendo recomendações para optimizar e facilitar a compreensão dessas restaurações.

O presente trabalho consiste numa revisão bibliográfica sobre a adesão de restaurações indiretas para dentes posteriores, focando essencialmente nas novas abordagens relativas a novas cerâmicas, preparação e técnicas de adesão.

A revisão da literatura foi realizada através da pesquisa de artigos nos bancos de dados Pubmed, Web of Science e Cochrane com as seguintes palavras-chave : (*bonding*) OU (*restaurações mini-invasivas*) OR (*cerâmica*) E (*preparações de dentes posteriores*). Foram incluídos artigos em inglês, francês e português publicados nos últimos 15 anos.

Palavras-chave: adesão, cerâmica, restaurações indiretas, dentes posteriores.

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LIST OF ACRONYMS

CAD/CAM: Computer-aided design/computer-aided manufacturing.

DEJ: Dentino-enamel junction.

E: Elastic modulus.

E&R: Etch and rinse.

Fe-SEM: Field-emission scanning electron microscopy.

Gpa: Gegapascal.

HF: Hydrofluoric acid.

IDS: Immediate dentin seal.

MDP: Methacryloyloxydecyl dihydrogen phosphate.

Mpa: Megapascal.

NCR: Nano-ceramic resins.

Ph: Potential of hydrogen.

PIAR: Posterior indirect adhesive restorations.

PICN: Polymer-infiltrated ceramics.

SBU: Scotchbond Universal.

SE: Self-etching adhesives

SEM: Scanning electron microscopy.

SIL: Silane.

TEM: Transmission electron microscopy.

VDO: Vertical dimension of occlusion.

ZLS: Zirconia-reinforced lithium silicate.

I. INTRODUCTION

Since their inception, fixed prostheses for prosthetic rehabilitations have been considered as a durable method for restoring the shape and function of damaged or missing teeth (Caracaş et al., 2021). In the mid-twentieth century, these approaches were primarily mechanistic, with cemented full coverage crowns being the predominant treatment option (Guastalla et al., 2005).

However, a significant paradigm shift occurred at the start of the second millennium, marking a true revolution in dentistry (Blatz et al., 2019). The introduction of bonding prosthetic parts to dental tissue overturned traditional stabilization and retention concepts, emphasizing adhesion (Sofan et al., 2017). This shift was driven by an increased understanding of dental organ importance and technological innovations focusing on tissue preservation, known as "tissue economy," and promoting biological, functional, and aesthetic integration of restorations (Tennert et al., 2022).

Subsequent research concentrated on enhancing materials, processes, and protocols to support this new therapeutic approach, enabling dental practitioners to offer conservative, minimally invasive, and precise prosthetic alternatives with excellent aesthetic and mechanical performance, termed adhesive dentistry (Perdigão et al., 2021).

As adhesive dentistry evolved, bonding became a cornerstone in dental practice, ensuring restoration retention while prioritizing conservation and aesthetics (Blatz et al., 2003). This evolution has led to numerous restorative solutions with varied approaches and materials. Adhesive techniques have profoundly altered the clinical landscape, changing the fundamental principles of traditional dentistry. The utilization of adhesion in restoration offers undisputable advantages, including conservation, sealing function, and aesthetics (Ferraris, 2017).

In this work, we are presenting the evolution of modern dentistry concepts. The first part of the work will focus on the evolution of ceramic materials, while the second part will cover different types of posterior adhesive restoration. In the final section, we will provide a detailed protocol and recommendations for successful posterior adhesive restorations.

II. DEVELOPMENT

1. CERAMIC RESTORATIVE MATERIALS

Advancements in adhesive technology, cements, and ceramic materials, coupled with rising patient aesthetic expectations, have expanded the applications of partial ceramic restorations, including inlays, onlays, and overlays. These restorations now offer the potential to achieve more seamless and precise results, closely mimicking the natural color of the tooth (Barrantes, 2020).

In dentistry significant advancements have been made in the past few years, driven by the emergence of new treatment methods, advancements in aesthetically focused dental materials, and the adoption of techniques that prioritize the preservation of dental tissues and organ integrity (Blatz et al., 2019).

Given the array of materials at their disposal, dental restoration success is highly dependent on the dentist's knowledge and skill with ceramic systems. Adequate knowledge enables appropriate material selection, effective management of diverse clinical scenarios, and alignment with patient expectations (Rekow et al., 2011).

A system of classification for dental ceramic materials serves multiple purposes, including facilitating education and communication. Ideally, such it should offer clinically relevant information regarding material suitability for different tooth locations (anterior or posterior), types of restorations (partial or full coverage , short or a long-span), and bonding methods (adhesive versus traditional) (Gracis et al., 2016).

Different features, including clinical indications, microstructure, composition, etchability, processing methods, firing temperatures, fracture resistance, translucency, and wear against antagonists, have been the focus of several proposed classification systems (I. L. Denry, 1996).

1.1. Definition

The American Society for Testing and Materials states that “a ceramic is a vitrified or unvitrified body of crystalline or partially crystalline structure or glass, the body of which is formed of essentially inorganic and non-metallic substances” (Jenkins & Salem, 2018).

Both the terms porcelain and ceramic are frequently employed interchangeably in the field of dentistry. The term ceramic is derived from the Greek word 'keramos', which specifically refers to a potter. This term pertains to the capacity to apply heat to clay and shape it into ceramics. Conversely, Marco Polo is credited for coining the term "porcelain" in the 13th century, derived from the Italian word 'porcellana' (Helvey, 2013). Clinicians are, therefore, faced with many possibilities and need a classification (Figure 1) that facilitates understanding and choice of the most appropriate ceramic system (Tirlet & Attal, 2009).

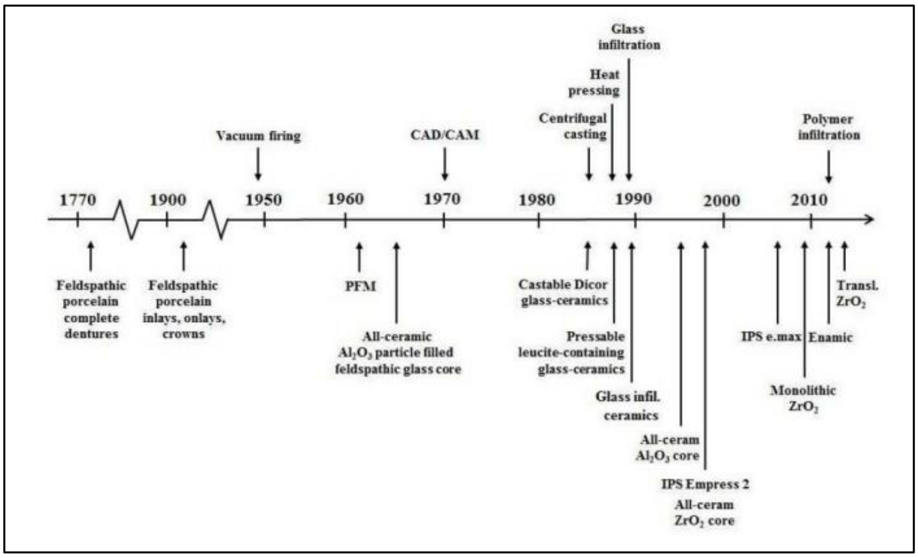


Figure 1: The chronology of the advancement of dental ceramics and their associated techniques for processing (Adapted from Zhang & Kelly, 2017).

Dental ceramics are defined as synthetic, inorganic, non-metallic materials, ionic, covalent, or ionocovalent bonded material obtained by high-temperature consolidation of a pre-formed powder agglomerate (Atlan, 2015). Ceramic materials are biocompatible, inert and safe to use in the oral cavity due to their excellent degree of intraoral stability (Warreth & Elkareimi, 2020).

This material has a mixed structure of glass and crystals, composed of 99% oxides (silicon oxides, aluminum oxides, zirconium oxides) carbides, nitrides and borides. It can be shaped using a variety of processes (Helvey, 2013).

Various classification systems have been proposed, focusing on composition, clinical indications, processing methods, etchability, microstructure, fracture resistance, translucency, and antagonist wear (Atlan, 2015).

1.2. Classification

The new system categorizes ceramic materials into three categories according on the aspects of chemical composition (Figure 2), they contain (Gracis et al., 2016):

- Glass-matrix ceramics: they are non-metallic and inorganic materials with glassy phase.

- Polycrystalline ceramics: they are inorganic and non-metallic materials that have only a crystalline without glassy phase.

- Ceramics with resin-matrix: they contain a polymer matrix that mainly comprises inorganic refractory compounds.

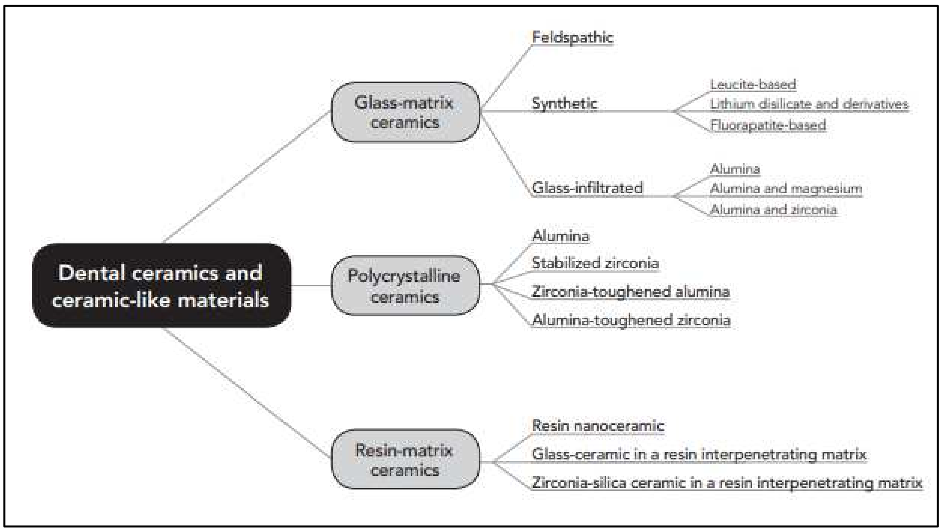


Figure 2 : Summary of the classification system for all-ceramic and ceramic-like materials (Adapted from Gracis et al., 2016).

The various phases that compose a material's chemical structure can affect its aesthetic appearance, as well as its mechanical properties. This includes properties such as high fracture toughness, low abrasive properties, flexural strength and wear resistance (Skorulska et al., 2021). Additionally, the sensitivity of ceramic materials to hydrofluoric acid can impact their ability to achieve a strong bond between resin and ceramic when etching (Bajraktarova-Valjakova et al., 2018).

1.2.1. Glass matrix ceramics

The first group, Glass-matrix ceramics, are a type of non-metallic, inorganic materials that are prepared by controlled crystallization of glasses using various processing techniques (Deubener et al., 2018). They are composed of one functional crystalline phase and residual glass, with a crystallized volume fraction ranging from parts per million to nearly 100%. These ceramics are categorized into three subgroups, namely feldspathic ceramics, synthetic ceramics, and glass-infiltrated (Helvey, 2013). They are often used in aesthetic restorations for anterior teeth because of their ability to resemble dental tissues, biocompatibility, chemical durability in the oral environment, and satisfactory mechanical properties (Vallerini et al., 2024).

1.2.1.1. Feldspathic ceramics

Traditional dental ceramics are composed of feldspar, quartz, and kaolin (Shi et al., 2022). Quartz is the primary material responsible for the restoration's translucency, making up 55-65% of the composition (Saint Jean S, 2014). However, it's not a strong substance, to enhance its strength, alumina (20-25%) is incorporated into the material. Kaolin is a hydrated aluminum silicate that makes up 4% of the composition, as it has opaque properties (Bajraktarova-Valjakova et al., 2018). It is used to bind the ceramic particles together. These materials continue to be employed as an aesthetic material attached to tooth structure and as a veneering material on ceramic substrates and metal alloy (I. Denry & Holloway, 2010, Deubener et al., 2018).

The most commonly applied feldspar-based CAD/CAM ceramics are VITABLOCS® from VITA Zahnfabrik, which have a typical size of the grains of 4µm and a flexural strength of 154MPa. VITA has introduced newer generations, such as VITABLOCS® TriLuxe (2003) and TriLuxe forte (2007), to replicate the natural colors of teeth. These generations have three and four layers with varying intensities of shade, respectively, making them appropriate for partial or full coverage crowns and veneers, in the anterior region (Sutejo et al., 2023). VITABLOCS® RealLife (2010) further enhances the replication of the natural teeth's shade gradient, with multichromatic feldspar ceramic featuring various color intensities in three dimensions. Following hydrofluoric acid surface etching the surface of VITA Mark II exhibits a multitude of micropores and channels with irregular particles of ceramic of various sizes, making it appropriate for encasing a composite luting cement (Bajraktarova-Valjakova et al., 2018; Warreth & Elkareimi, 2020).

Feldspathic ceramics are known to have low mechanical strength, with a flexural strength of around 60-70 MPa. Over the years, several attempts have been made to improve the properties of this material. One notable example is the work of Mac Lean and Hugues in 1965. By incorporating up to 50% alumina, they were able to obtain a ceramic with a flexural strength of 120-150 Mpa. This improvement allowed for a broader range of clinical applications. Additionally, these ceramics have excellent optical properties due to their high ability to conduct light, with a refractive index similar to that of enamel and dentin (Shi et al., 2022).

This ceramic can be indicated for veneers, chips on anterior teeth, as well as for cosmetic crowns and bridges with a metal or ceramic base (Montazerian et al., 2023).

1.2.1.2. Synthetic glass-ceramics

Synthetic glass-ceramics have gained widespread use due to their impressive qualities, which include chemical stability, biocompatibility, translucency and mechanical strength. As a result, they're commonly utilized as non-retentive bonded restorations (Vallerini et al., 2024).

These ceramics have a greater abundance of crystalline phase, which decreases the likelihood of fracture development or retards the spread of cracks if they have already formed. Crystals enhance the mechanical qualities of the ceramic material (Gracis et al., 2016).

Glass-ceramics have a microstructure composed from dispersed crystals encased in a translucent glassy phase or matrix. The glassy phase includes the usual characteristics of glass, including translucency, non-directional fracture pattern, and brittleness. The crystalline phase enhances opacity and light scattering, which allows the ceramic material to adapt to the color of enamel and dentin. It also provides the ceramic material with stability during firing, strength, and resistance to stresses that occur in the mouth (I. Denry & Holloway, 2010).

The ultimate mechanical characteristics of synthetic glass ceramics are influenced by two categories of variables, intrinsic and extrinsic. Intrinsic factors encompass characteristics such as the size, number, and geometry of crystals, as well as the distribution pattern of the crystals (homogeneity). Extrinsic factors, on the other hand, include conditions related to fabrication and the oral environment, such as humidity, variations in cyclic loading, thermos shocks and pH level. Lithium disilicate, leucite-reinforced, fluorapatite-based ceramics and zirconia-reinforced lithium silicate are examples of synthetic glass ceramics (I. Denry & Holloway, 2010; I. L. Denry, 1996).

a- Lithium disilicate and derivatives

Lithium silicate ceramics have the highest strength among all silicate ceramics, boasting a flexural strength of around 407 MPa. This ceramic was introduced on the market in 1998, with the launching of IPS Empress 2 (Skorulska et al., 2021).
Derived from the crystallization of a SiO2-Li2O precursor glass into two types of crystal structures: lithium disilicate (Li2Si2O5) and smaller amounts of lithium metasilicate (Li2SiO3), which are uniformly dispersed in the glass phase. The crystals make up approximately 70% of the glass-ceramic volume. The final microstructure is composed of thickly interlocked lithium disilicate crystals measuring 0.8 µm in diameter and 5 µm in length (Figure 3). Additionally, the layered crystals and interlocked microstructure are likely to contribute to the material's strength (Figure 4) (I. Denry & Holloway, 2010).

Figure 3: Heat-pressed lithium disilicate glass-ceramic microstructure (Adapted from I. Denry & Holloway, 2010).

Figure 4 : Crystals interlocked in glass-ceramic lithium disilicate (Adapted from I. Denry & Holloway, 2010).

To shape the platelet-like microstructure of lithium disilicate crystals, they must be in a partially crystallized "blue state" of lithium metasilicate. This state has a flexural strength of 130 Mpa, making it easy to mill the blocks. The final microstructure of the material is controlled by heat treatment (Skorulska et al., 2021).

This ceramic material has a wide range of applications. It can be used to produce various partial prosthetic parts, including anterior restorations like veneers or chips, as well as posterior restorations such as onlay, inlay, overlay, endocrown. Additionally, it can also be used for the fabrication of monolithic anterior and posterior infrastructures, crowns, and small anterior bridges (Vallerini et al., 2024).

b- <u>Leucite-based</u>

This ceramic is made by processing two basic glasses from an amorphous state to a heterogeneous glass-ceramic state. It has a crystalline content of 45% by volume, consisting of leucite that is fired at 1200°C, pressed in molds, and stabilized in its cubic form (Figure 5). The crystals are homogeneously distributed within the glass matrix (I. Denry & Holloway, 2010).

This ceramic exhibit enhanced translucency, fluorescence, and opalescence due to its high silica content (60-65%) (Bajraktarova-Valjakova et al., 2018). Additionally, its flexural strength of 160 MPa is attributed to its crystalline composition, which also enables it to absorb fracture energy, leading to the arrest or deceleration of crack propagation (Montazerian et al., 2023).

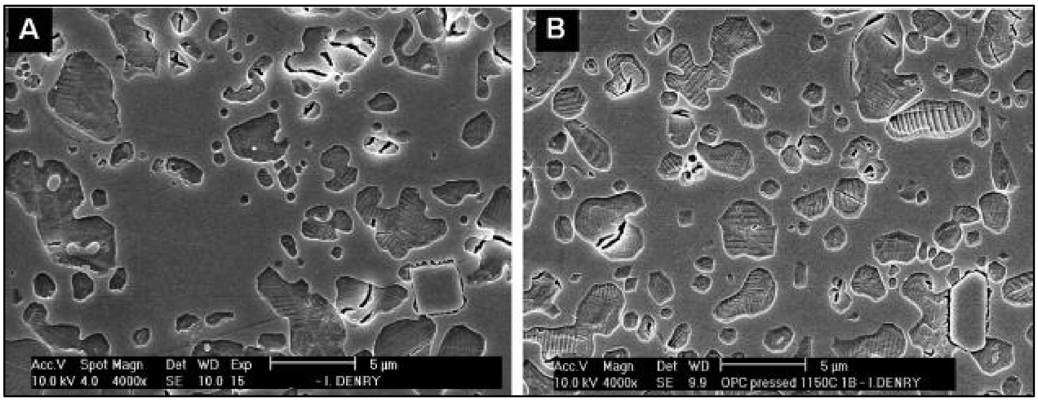


Figure 5 : (a)Feldspathic dental porcelain, (b) First generation heat-pressed leucite reinforced ceramic (Adapted from I. Denry & Holloway, 2010).

The enhanced strength of leucite-reinforced glass-ceramics, which is approximately double that of conventional feldspathic ceramics, signifies notable progress in dental materials. However, it is not strong enough to be used for bridges in the posterior region. Therefore, its application will be limited to veneers, onlays, inlays, anterior and posterior single crowns (Skorulska et al., 2021).

c- Fluorapatite-based

It is a glass-ceramic material characterized by fluorapatite crystals [Ca5(PO4)3F] dispersed within a glass matrix (Figure 6) (Montazerian et al., 2023). Its flexural strength is comparatively lower, ranging from 90 to 110 MPa, compared to other all-ceramic materials, which are used in the manufacture of prosthetic infrastructures and frameworks. Fluorapatite-based ceramic can be used for veneers or as a glazing material for lithium disilicate frameworks (Gracis et al., 2016; Saint Jean S, 2014).

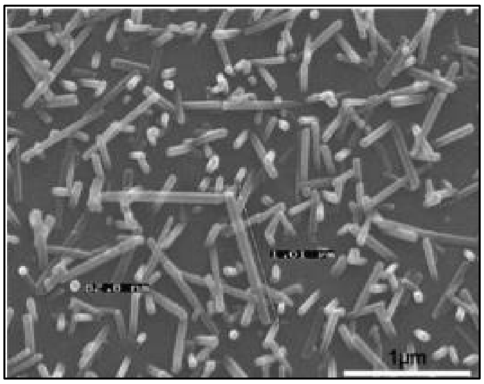


Figure 6 : SEM micrograph of fluorapatite glass-ceramic (etched in 2.5% hydrofluoric acid for 10 seconds) (Adapted from Saint Jean S, 2014).

d- Zirconia-reinforced lithium silicate

Since 2013, lithium disilicate ceramics have been strengthened by adding up to 10% zirconium oxide by weight to the precursor glass. The blocks are available in two forms: fully crystallized (Celtra Duo, Dentsply®) or partially crystallized (Suprinity, Vita®), which requires additional heat treatment (Traini et al., 2016).

However, in order to achieve mechanical properties similar to those of glass-ceramics (with a bending strength of 370 MPa after glazing), ceramics require polishing, staining and glazing. Nevertheless, the thermal incompatibility between crystals and the zirconium oxide-containing glass phase results in residual stress, which causes microcracking on cooling and decreases the reproducibility of mechanical properties (Traini et al., 2016). Zirconia-doped glass ceramics, with very fine particles of zirconia-reinforced lithium silicate (ZLS), allow for better optical properties, light transmission aesthetic appearance, opalescence and fluorescence. Hence, their indications are similar to those of lithium disilicate glass-ceramics owing to the similarity between the two materials (Bajraktarova-Valjakova et al., 2018).

The zirconia-reinforced lithium silicate (ZLS) surface treatment that involved applying 4.9% HF gel for 20 seconds demonstrated the greatest results in terms of microstructure retention; however, when the etching period was increased to 40 seconds, the ZLS microstructure's surface deterioration became apparent. Meanwhile, increasing the hydrofluoric acid concentration to 9.5% for 20 or 40 seconds causes the ZLS material to become more and more deformed on the surface (Figure 7) (Traini et al., 2016).

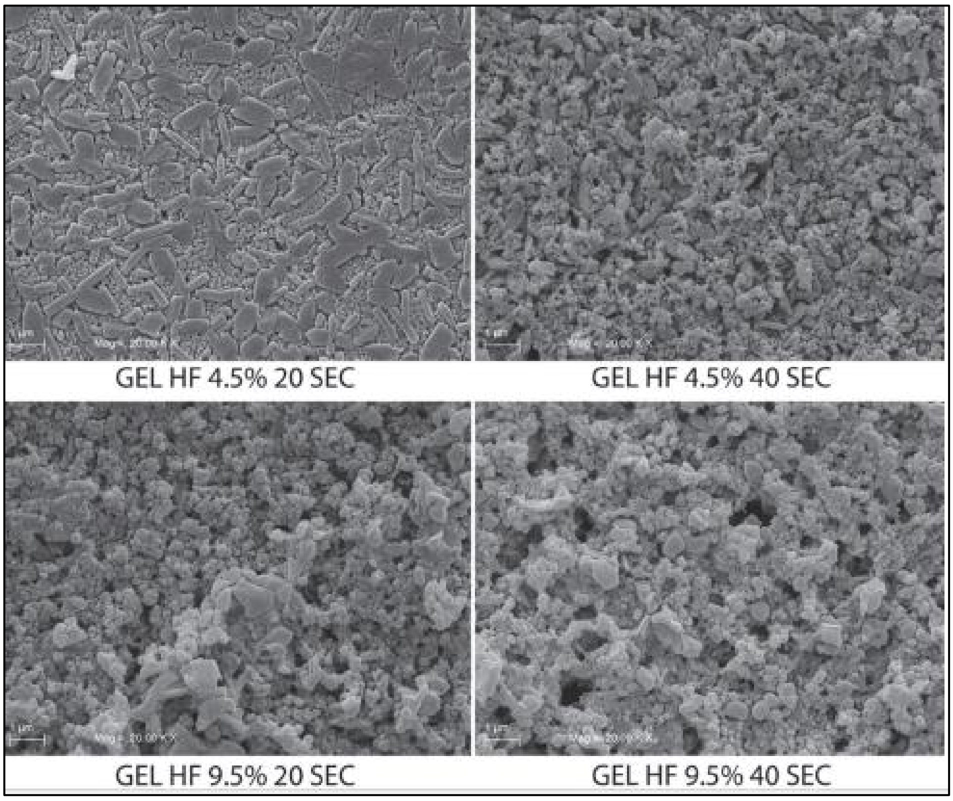


Figure 7 : The zirconia-reinforced lithium silicate surface treatment (Adapted from Traini et al., 2016).

The table below summarizes the properties of feldspathic and synthetic glass matrix ceramics (Table 1).

Table 1 : Properties of feldspathic and synthetic glass matrix ceramics.

	Mechanical properties			**Optical properties**	**Bonding**	**Indications**
	resistance to bending (MPa)	Toughness (MPA/m2)	Elasticity (Gpa)			
Feldspathic ceramics:	60-70	1.26	70	+++	+++	Veneers Chips cosmetic crowns and bridges with a metal or ceramic base.
Lithium disilicate	360	2,25-2,75	95-102	++	+++	Veneers or chips, inlay,onlay, , overlay, endocrown. monolithic anterior and posterior crowns, small anterior bridges
Leucite-based	160	1.3	62-70	++	+++	Veneers or chips, inlay,onlay monolithic anterior crowns
Fluorapatite-based	90	0.7-1	60-80	+++	+++	Used as veneering materials over zirconia substructures or metal alloy
Zirconia-reinforced lithium silicate	370-420	2.6	70-108	++	+++	Veneers or chips, inlay,onlay, , overlay, endocrown. monolithic anterior and posterior crowns,

1.2.1.3. Glass-Infiltrated ceramics

Glass-infiltrated ceramics are a type of ceramic-glass composite characterized by the presence of at least two interpenetrating phases within the material. The optical final and strength properties of these ceramics are determined by the chemical composition of their porous core (Gracis et al., 2016).

The table below summarizes the compositions, properties and indication of Glass-infiltrated ceramics (Table 2).

Table 2 : Compositions, properties and indication of Glass-infiltrated ceramics.

	Composition	Properties	Indications
VITA In-Ceram™ SPINELL	alumina and magnesia	high translucency low strength (400 MPa	-Single crowns in the anterior region.
VITA In-Ceram™ ALUMINA	80%,alumina	Optimal translucency strength (500 MPa),	-Single crowns in both anterior and posterior regions -3-unit bridges in the anterior region
VITA In-Ceram™ ZIRCONIA	alumina and zirconia	highest bending strength (600 MPa)	-Single crowns in the posterior region -3-unit bridges regardless

The difference is not statistically significant in the fracture toughness and flexural strength between In-Ceram™ ALUMINA and In-Ceram™ ZIRCONIA. Moreover, the superficial microstructure of these ceramics remains unaffected by acid etching with HF acid. Nevertheless, the utilization of this material category is diminishing due to the intricate and delicate manufacturing process involved, alongside the rising preference for lithium disilicate ceramic and zirconia materials (Bajraktarova-Valjakova et al., 2018).

1.2.2. Polycrystalline Ceramics

They are industrially produced. Their main characteristic is a dense crystalline structure without a glassy matrix. They are resistant to surface etching with hydrofluoric acid (Gracis et al., 2016).

The material's fracture toughness and high strength are due to the crystals being arranged in regular arrays, which reduces crack propagation (Bajraktarova-Valjakova et al., 2018).

1.2.2.1. Alumina

This material is composed of high-purity Al2O3, with a purity of up to 99.5%. It was initially presented by Nobel Biocare in the mid-1990s as a primary material for CAD/CAM fabrication. With a high hardness range of 17 to 20 GPa and a relatively strong structure, it has proven to be a reliable option. However, its elastic modulus (E = 300 GPa), which is the highest among all dental ceramics, has made it susceptible to bulk fractures. Because of this vulnerability, as well as the emergence of materials with improved mechanical properties, such as stabilized zirconia's transformation toughening capabilities, the use of alumina has declined (Bajraktarova-Valjakova et al., 2018; Gracis et al., 2016).

1.2.2.2. Stabilized zirconia

Yttrium-stabilized polycrystalline tetragonal zirconia, commonly known as traditional zirconia, is the first generation of zirconia, it's classified into 12 types based on the yttria content (Figure 8) (Kongkiatkamon et al., 2023).

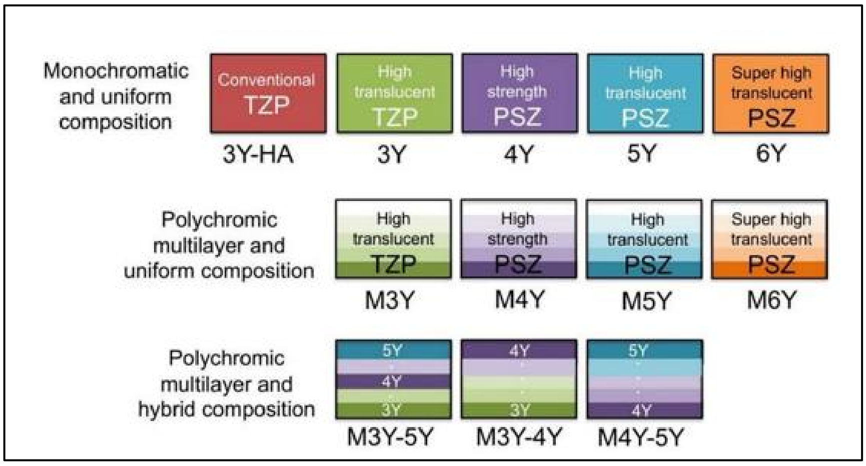


Figure 8: Classification of yttria-stabilized dental zirconia (Adapted from Kongkiatkamon et al., 2023).

Zirconia is a durable and stable biomaterial used for dental restorations. It has a very low thermal conductivity, greater radio-opacity and flexural strength ranges from 1000 to 1400 Mpa (Figure 9). Compared to glass-ceramics, its translucency is little lower, yet it is still an esthetic biomaterial (Kongkiatkamon et al., 2023; Yin et al., 2024).

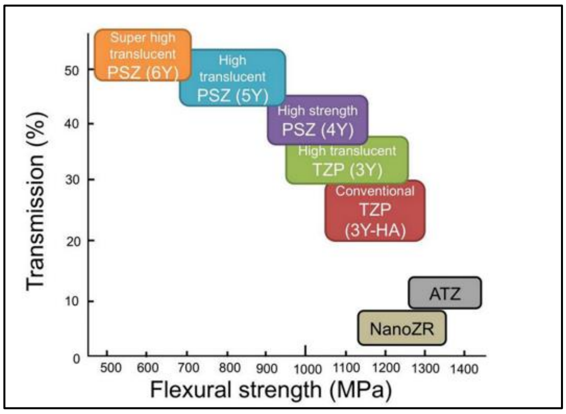


Figure 9 : Dental zirconia translucency vs flexural strength (Adapted from Kongkiatkamon et al., 2023).

Establishing adhesion between zirconia and resin cement poses difficulties due to their chemical inertness and limited silica content. To address this challenge, various surface treatments for zirconia have been developed to improve bonding to the tooth structure. These treatments typically involve methods such as airborne particle abrasion and tribo-chemical silica coating (Kongkiatkamon et al., 2023). A commonly employed technique includes the use of alumina particles afterward by the application of primers or cement containing 10 MDP. Nevertheless, zirconia can be used in various indications, from crowns to extended bridges (I. Denry & Holloway, 2010).

It is interesting to note that the grain size of 3Y-TZP has a significant influence on both its stability and mechanical characteristics. When the grain size of 3Y-TZP exceeds a critical limit, it becomes less stable and more susceptible to spontaneous transformation. Conversely, smaller grain sizes are related to a lower rate of transformation (Figure 10) (I. Denry & Holloway, 2010).

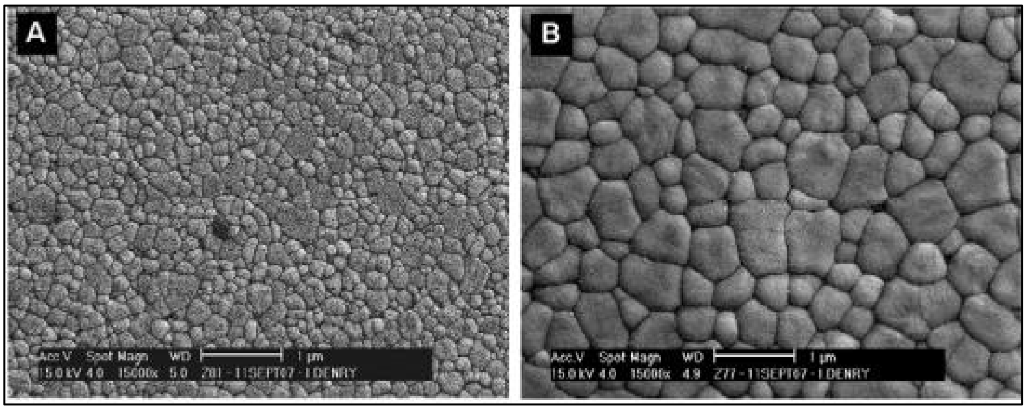


Figure 10: 3Y-TZP ceramic sintered at (1) 1300 °C for 2 hours (2) 1500 °C for 2 hours (Adapted from I. Denry & Holloway, 2010).

In 2011, a new type of translucent monolithic zirconia was introduced to solve the issues of chipping and poor optical properties that traditional zirconia had (Figure11) (Stawarczyk B, 2017). This new material possesses good mechanical and aesthetic properties which makes it suitable for both anterior and posterior sectors (Bajraktarova-Valjakova et al., 2018).

Figure 11: Comparison of the different zirconium oxide generations compared to LiSi2 ceramic (Adapted from Stawarczyk B, 2017).

Since then, there have been three ways of producing translucent zirconia which led to the emergence of new generations of the material. The first method involves making the 1st generation zirconia more translucent by modifying the firing cycle and increasing the firing temperature. This results in grain coarsening which in turn reduces the number of grain boundaries, thus allowing more light to pass through (Kolakarnprasert et al., 2019; Zhang & Lawn, 2018).

The second-generation 3Y-TZP zirconia were obtained by reducing the proportion of Al2O3 that was homogeneously distributed outside of zirconia granules in the form of fine particles (Figure 12). The third generation 5Y-TZP zirconia contains more than 50% cubic phase that is stabilized with 5% moles of yttrium oxide (Abu-Naba’a, 2023). The cubic grains have an isotropic refractive index, which reduces high light scattering (Stawarczyk B, 2017).

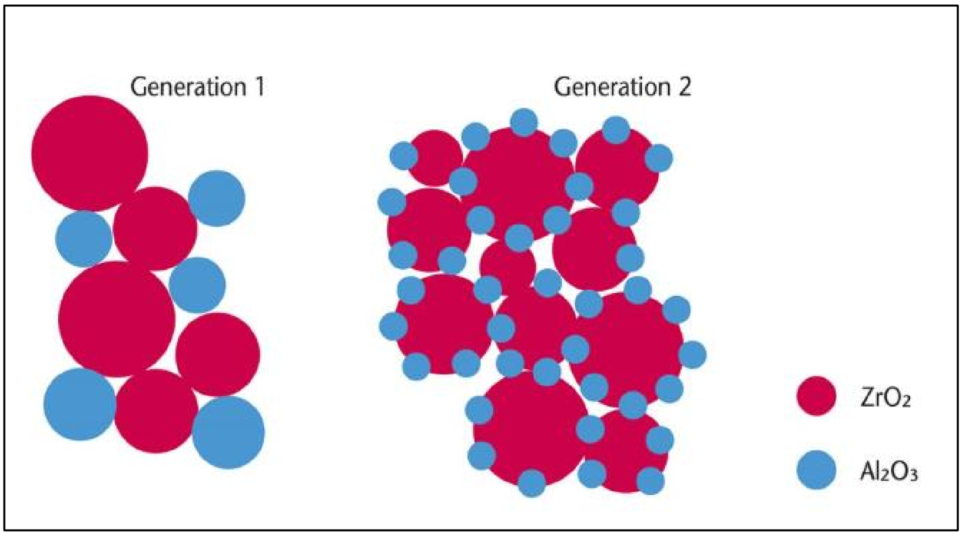


Figure 12: Graphical comparison of the structure of the 1st and 2nd generation zirconium oxides (Adapted from Stawarczyk B, 2017).

Figure 13 shows the flexural strength values of the generations. In summary, it must be emphasized at this point that the 1st generation zirconium oxide provides the significantly highest strength values. The 3rd generation zirconium oxide, on the other hand, shows the significantly lowest strength values (Stawarczyk B, 2017).

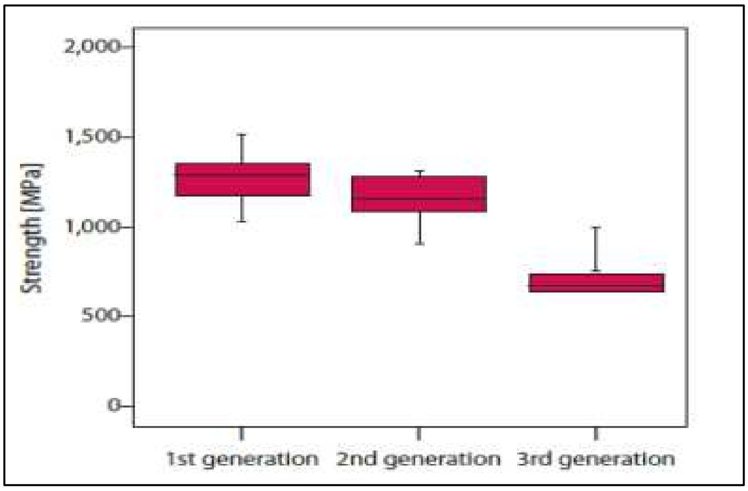


Figure 13: Comparison of the strength of different generations of zirconia (Adapted from Stawarczyk B, 2017).

Despite all the efforts made to improve the translucency of zirconia, it is widely accepted that even the most translucent forms of zirconia exhibit less translucency than lithium disilicate when the thickness surpasses 0.5 mm. It is advisable to limit the use of translucent zirconia to small single-unit restorations (such as crowns, veneers, and inlays) and 3-unit bridges while respecting the exact preparation requirements applied to conventional zirconia. However, it is possible to fabricate very thin restorations of 0.5 mm according to several in vitro studies (Stawarczyk B, 2017; Zhang & Kelly, 2017).

1.2.2.3. Zirconia-toughened alumina and alumina-toughened zirconia

For arthroplasty applications, ceramics are being developed by combining zirconia and alumina. Zirconia retains partial stabilization in the tetragonal phase, whereas alumina has moderate toughness. They were introduced for the first time by Claussen in 1976 (Clausen & Steeb, 1976; Gracis et al., 2016).

Improved control of the tetragonal-monoclinic phase transformation has resulted in materials that have mechanical properties such as toughness and flexural strength that exceed those of their constituent components. Graded alumina and graded zirconia are recent material developments that have not yet been made available to the profession. These restorative materials are a variant of polycrystalline materials, where glass is introduced into alumina or zirconia substrates via infiltration. This infiltration improves the performance of the system by making it more resistant to damage, which enhances performance. This approach offers promising new possibilities for the creation of more thin dental restorations with robust biomechanical and aesthetic properties (Gracis et al., 2016).

1.2.3. Resin matrix ceramic

According to Shetty, resin matrix ceramics are materials made up of a combination of organic polymers and inorganic refractory fillers, which are typically ground ceramics (Shetty et al., 2015). This results in a hybrid material with unique properties, as both organic and inorganic elements coexist within it. These materials share a similar chemical composition, with the inorganic component making up over 60% of the weight in the form of ceramic particles. The organic component consists of a resinous matrix made up of polymers (Skorulska et al., 2021).

This class of ceramics comprises two categories of materials: dispersed-phase materials and polymer-infiltrated ceramics (Bajraktarova-Valjakova et al., 2018).

1.2.3.1. Dispersed-phase materials

First introduced in conservative dentistry in the 2000s, these materials are manufactured from composite resins inserted in a plastic phase. They combine a resin matrix with ceramic fillers (Hassan et al., 2023). A distinction is made between two composites, which differ mainly in the size of their ground ceramic particles:

o Nano-Ceramic Resins (NCR): nanometric ceramic particles (Figure 14).

o With zirconia-silica particles of micrometer size.

Their microstructure is similar to composite resins, the ceramic particles are randomly dispersed within the polymer matrix. Polymerization is carried out industrially at high temperatures (Zhang & Lawn, 2018).

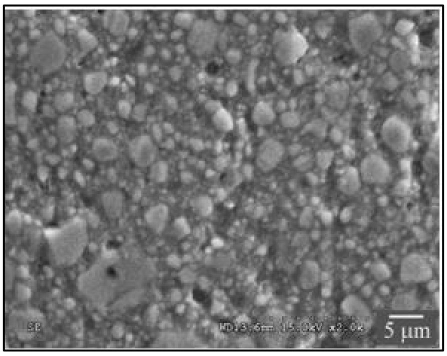


Figure 14: SEM view of NCR Lava Ultimate® ceramic (Adapted from Zhang & Kelly, 2017).

The NCR's elastic properties provide convenient intraoral milling and repair. Intraoral repair is considered a conservative and cost-effective procedure with a lesser risk of pulpal damage, in contrast to the total replacement needed for failing traditional ceramic materials. Wear resistance is a crucial factor that significantly impacts clinical performance (Hassan et al., 2023).

1.2.3.2. Polymer-infiltrated ceramics (PICN)

This material was invented by Dr. Michael Sadoun in France and was launched in the year 2012. It has a dual-network structure comprising of ceramic (86%) and composite resin (14%). The manufacturing process is based on the In-Ceram® ceramic method, which involves infiltrating a ceramic matrix with polymers (Figure 15). This process results in two distinct networks of ceramic particles and polymer matrix that are interconnected and interpenetrated, forming a true skeleton. Polymerization takes place at high temperature (180°C) and high pressure (HP = 300 MPa) (Bajraktarova-Valjakova et al., 2018).

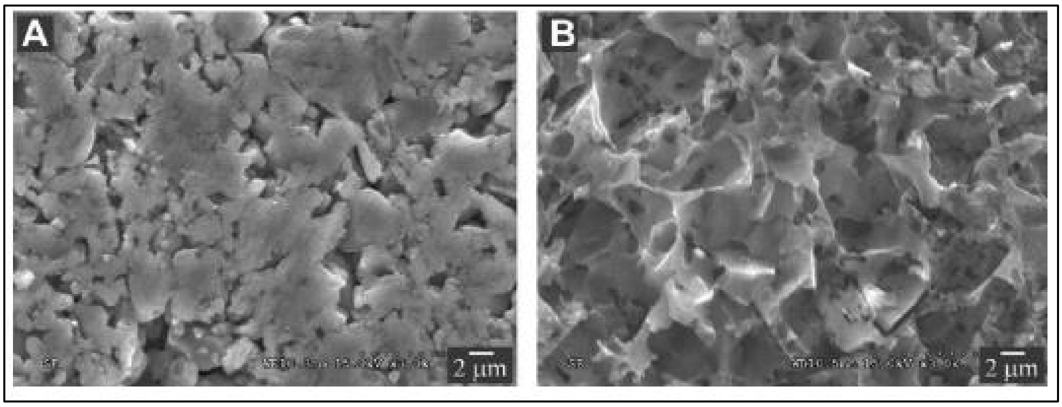


Figure 15: SEM view of PICN Vita Enamic® ceramics (Adapted from Zhang & Kelly, 2017).

1.2.3.3. Clinical application of Resin matrix ceramic

Resin-matrix ceramics are known for their modulus of elasticity, giving them a soft and less rigid quality than other ceramics (Bajraktarova-Valjakova et al., 2018). These materials are excellent for dental restorations because they distribute occlusal loads more evenly between the restoration and residual tissues, reducing the risk of cracks, fractures, or delamination. Resin-matrix ceramics are also highly flexible and rigid, making them suitable for bonded restorations (Gracis et al., 2016). They have a higher fatigue strength than glass ceramics, making them ideal for use in unstable occlusal situations (parafunction or bruxism). Additionally, due to their high ceramic content, they have bonding values close to those of vitreous ceramics. Finally, resin-matrix ceramics are aesthetically pleasing because they are light-transmissive, light-scattering, and have a fluorescence similar to that of natural dental tissue, making them great biomimetics (Alves de Lucena M et al., 2021).

Resin-matrix ceramics are available in various translucencies and multicolored blocks. These materials have a remarkable machinability and are not brittle, making them flexible and low in hardness. This allows for smoother restorations and greater precision in the clinical adaptation of prosthetic parts. The materials can be manufactured in thin thicknesses of 0.5 to 0.3 mm, which makes them suitable for more conservative restorations that respect residual tooth structure. They are preferred for restorations bonded to unprepared teeth, and their use in thin thicknesses gives them remarkable aesthetic properties, as their translucency is equivalent to enamel (Çelik & Göktepe, 2019).

1.3. Classification Summary of All-Ceramic and Ceramic-like Restorative Materials

The table below summarizes the fabrication processes, the ability to be etched for adhesive cementation, and the manufacturers clinical indications (Table 3).

Table 3: An overview of the fabrication processes, the ability to be etched for adhesive cementation, and the manufacturers clinical indications.

		Fabrication method	Etchable	Clinical applications
Glass-matrix ceramics				
	Feldspathic ceramics	Refractory die, platinum foil, press	*YES*	-Veneers, anterior crown -Inlays, onlays, partial restoration -Posterior crowns, -Veneering CAD/CAM material for bridge
Synthetic ceramics				
	Leucite-based	Press or CAD/CAM	*YES*	-Veneers, anterior crown -Inlays, onlays, partial restoration -Posterior crowns, -Veneering CAD/CAM material for bridge
	Lithium disilicate and derivatives	Press or CAD/CAM	*YES*	-Veneers, anterior crown -Inlays, onlays, partial restoration -Posterior crowns, -3-unit bridges (anterior and premolar) -Hybrid abutments, hybrid abutment crowns; -3-unit posterior bridges -Veneering CAD/CAM material of multi-unit bridge substructure made of IPS e.max ZirCAD

	Fluorapatite-based	Press or layering	*YES*	Veneering materials over zirconia substructures or metal alloy
				-Veneers or chips, -Inlay,onlay,overlay, endocrown. -Monolithic anterior and posterior crowns,
Glass-infiltrated				
	. Alumina	CAD/CAM or Slip-casting	*YES*	-Single crowns in both anterior and posterior regions -3-unit bridges in the anterior region
	Alumina and magnesium	CAD/CAM or Slip-casting	*YES*	-Single crowns in anterior region
	Alumina and zirconia	CAD/CAM or Slip-casting	*YES*	-Single crowns in both anterior and posterior regions, -3-unit bridges in the anterior region
Polycrystalline ceramics				
	Alumina	CAD/CAM	*NO*	-Fixed partial denture. -Single crowns in both anterior and posterior regions, veneer
	Stabilized zirconia	CAD/CAM	*NO*	Fixed partial denture, Single crowns in both anterior and posterior regions,implant-supported crowns Partial coverage restoration
	Zirconia-toughened alumina and alumina-toughened zirconia	CAD/CAM	*NO*	Fixed partial denture, Single crowns in both anterior and posterior regions, Implant-supported crowns Partial coverage restoration
Resin-matrix ceramics				
.	Resin nanoceramics	CAD/CAM	*NO*	Veneers, anterior and posterior crowns, inlays, onlays
	Glass-ceramics in a resin interpenetrating polymer network	CAD/CAM	*YES*	Veneers, anterior and posterior crowns, inlays, onlays

	Zirconia-silica in a resin interpenetrating polymer network	CAD/CAM	*NO*	Veneers, inlays, onlays, anterior and posterior crowns

2. DIFFERENT TYPES OF INDIRECT CERAMIC RESTORATION IN POSTERIOR TEETH

The use of adhesive techniques in restorative and prosthetic dentistry has revolutionized treatment. These techniques allow for a more conservative approach to treatment, resulting in less tissue damage and improved pulp vitality (Vincent et al., 2022). Advances in understanding the mechanisms of adhesion to mineralized tissues, as well as the development of new composite and ceramic biomaterials, have expanded the indications for bonded partial restorations (Manuja et al., 2012). This reliable alternative to conventional full coverage crown is even effective in cases of severe decay, bonded restorations do not require significant tissue mutilation or periodontal aggression. Additionally, pre-prosthetic endodontic treatments are often unnecessary with bonded restorations, as they allow for increased coronal retention without compromising the root anchorage (Perdigão et al., 2021). Overall, bonded restorations provide a significant advantage in preserving pulp vitality and pushing the limits of conservative treatment (Dietschi D, 2007).

Therefore, analysis of the residual structure will be the main factor to be considered in our choice of treatment. Other factors, such as the occlusal and esthetic context or the tooth's location, will also be essential to objectify (Dietschi et al., 2008). Molars are often a more favorable situation than premolars, with a larger bonding surface and pulp chamber and their masticatory forces applied mainly in compression. On the other hand, Premolars are subject to more harmful lateral shearing forces (D’Incau & Bartala, 2011). Our approach is based on the concept of the "therapeutic gradient" described by ATTAL and TIRLET (although initially described for restorations in the esthetic sector), which is based on the application of the least mutilating technique for a given situation in order to achieve a functional and esthetic result (Tirlet & Attal, 2009).

Modern dentistry offers a range of restorative solutions that use different approaches and materials. Adhesive techniques have significantly changed the clinical scenario by making restorations more predictable (D’Incau & Bartala, 2011). Posterior indirect adhesive restorations are commonly used to restore cavities with extended coronal destruction. These restorations are commonly used to treat cavities with extensive coronal damage, allowing for healthy tissue preservation. The specific type of restoration required depends on the type of cavity being treated. There are several types of restorations, going at least to the most invasive (Figure 16), including inlays indicated for cavities that do not require cuspal coverage, onlays are using for cavities that require coverage of one or more cusps, overlay, which is a specific onlay typology with complete cuspal coverage, veneerlay which like an overlay with the involvement of the buccal wall and preparation combined with a laminate veneer, endocrown which is like an overlay with a pulp chamber retention and finally the full coverage crown (Ferraris, 2017).

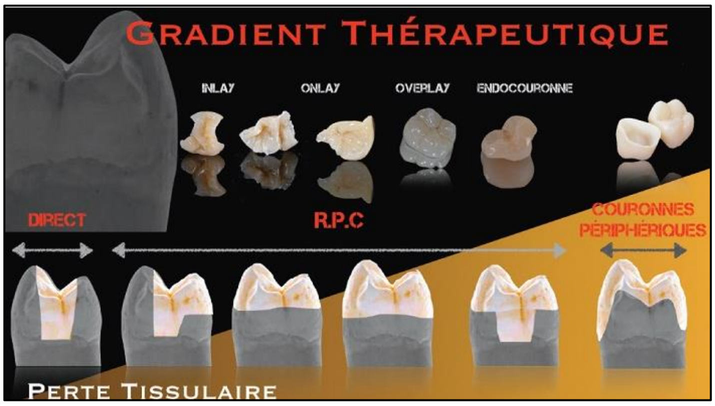


Figure 16: Therapeutic gradient posterior teeth (Adapted from Bonnafous, 2018).

2.1. Definition

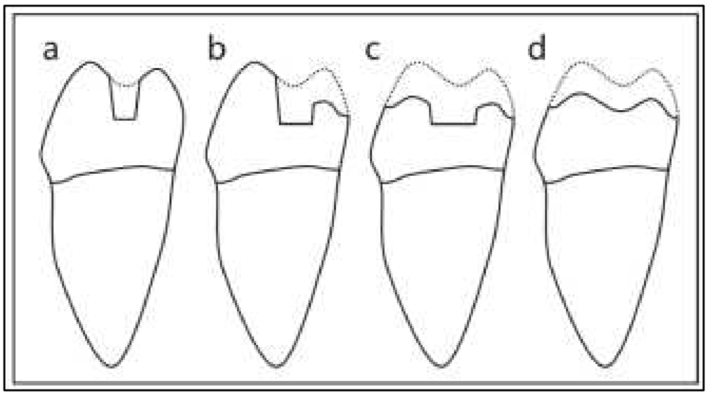


Figure 17: Types of restorations: inlay (A), onlay (B), overlay (C, D) (Adapted from Fan et al., 2021).

2.1.1. Inlay

An inlay is a dental restoration that is made outside of the mouth to match the shape of the prepared cavity and the natural shape of the tooth. It is applied to the tooth without covering the cusps and is usually cemented or adhesively bonded (Figure 17A).

Inlays are commonly used to repair medium to large class-II cavities where the buccal and lingual walls are still well-preserved (Sultan et al., 2021).

Ceramic inlay restorations are commonly used in aesthetic dentistry due to their durability, ability to match the color of teeth, and anatomical shape stability (Pawar et al., 2022). These restorations are best suited for teeth that are not under significant occlusal stress, as placing ceramic inlays in these teeth can result in more predictable long-term performance (Mandal et al., 2022). Studies have shown that ceramic inlays have a high survival rate and a low failure rate in posterior teeth (Pawar et al., 2022). In terms of clinical performance, ceramic partial coverage restorations, such as feldspathic porcelain and glass-ceramic, have been found to outperform resin restorations both at 5-year and 10-year follow-up (Buduru et al., 2022). However, while the traditional method of creating ceramic inlays allows for a high level of customization, digital techniques offer advantages such as fewer laboratory stages and quicker changes.

At 5, 8, 10, 12, 15, 18, and 20 years, the estimated survival rate for all-ceramic inlays are 98.9%, 97.3%, 96.8%, 89.6%, 87.2%, 81.5%, and 81.5%, correspondingly (Beier et al., 2012). The failures were attributed to fractures/chipping in 4% of cases, followed by endodontic complications in 3%, secondary caries in 1%, debonding in 1%, and severe marginal staining in 0% (Montazerian et al., 2023).

2.1.2. Onlay:

A ceramic onlay is a type of dental restoration that covers a part of the tooth, including one or more cusps and the occlusal surface (Figure 17B) (Sultan et al., 2021).

It is typically held in place using conventional bonding or resin cements. Onlays are recommended when the distance between the buccal cusp tip and the lingual cusp tip is greater than the width of the isthmus, or when a cusp is weak (Fan et al., 2021).

At 5, 8, 10, and 12 years, ceramic onlays have respectively 98.9%, 98.1%, 92.4%, and 92.4% survival probabilities (Beier et al., 2012). Meanwhile, the success rates of ceramic onlays was 88% after 5 years and 77% after 10 years (Fan et al., 2021; Mandal et al., 2022).

In 2017, Otto conducted a study on 200 bonded partial restorations and published the results. The study reported a survival rate of 87.5% after 27 years. The failures were classified into the following categories:

- 65% of failures were due to ceramic fracture
- 13% of failures were caused by tooth fracture
- 18% of failures were linked to the onset of secondary caries
- 4% of failures were caused by secondary endodontic problems (Otto, 2017).

Main preparation criteria for cosmetic inlays/onlays (D'Incau & Zunzarren, 2014).

- The angles formed between the floor and the axial walls need to be rounded (Figure 18 a).
- The internal walls should have a divergence that is not excessively restricted (≥ 10°) (Figure 18 b).
- The cavo-superficial limits must be clear, with no bevel (Figure 18 c).
- Occlusal impacts should not be situated at the tooth-restoration interface (Figure 18 d).
- The width of the main isthmus must be more than 2mm (Figure 18 e).
- The proximal box must have a mesio-distal width of at least 1mm (Figure 18 f).
- Restorations should be 2 mm thick at the occlusal groove (Figure 18 g).
- Residual wall width should be at least 1 mm at occlusal level and 2 mm at the cervical level (Figure 18 h).
- The restorative materials (composite or ceramic) should have a minimum thickness of 1.5 to 2 mm for covering the cusps (Figure 18 i).
- A filleted margin is recommended at covered cusps (Figure 18 j).

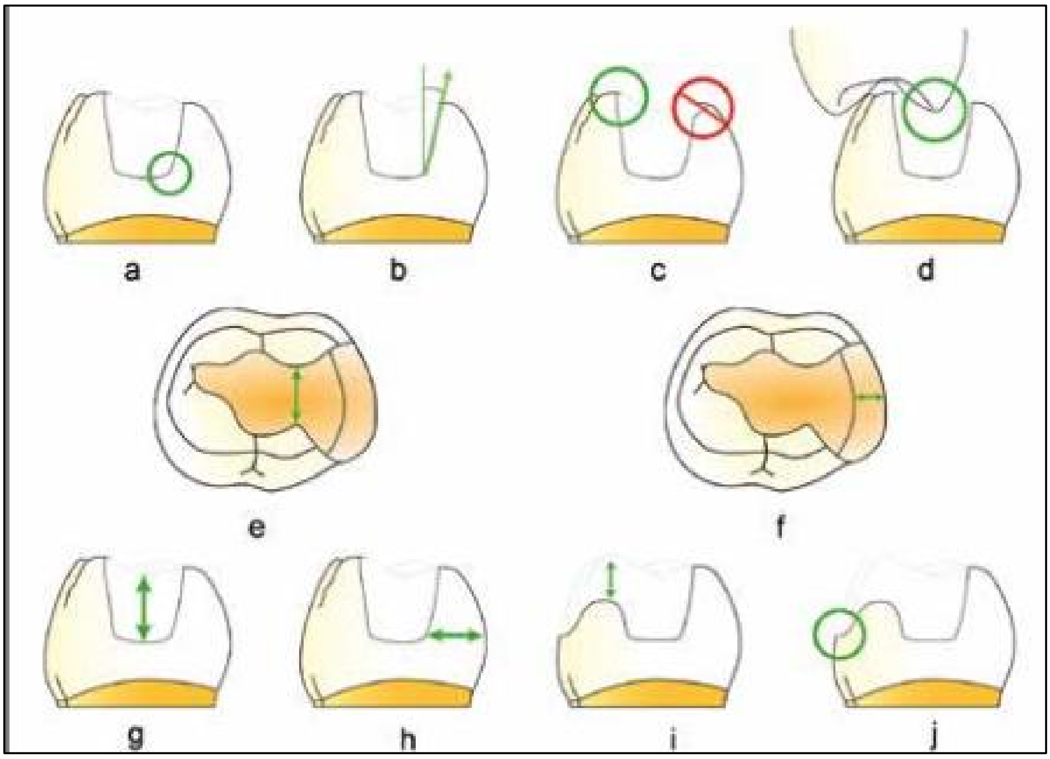


Figure 18: Main preparation criteria for inlay onlay (Adapted from D'Incau & Zunzarren, 2014).

2.1.3. Overlay

An overlay is a type of onlay that covers all the cusps and is bonded using adhesive (Figure 17C) (Étienne & Watzki, 2017). The main reasons for using onlays and overlays, according to Ferraris, are filling medium to large cavities if one or more cusps are absent; modifying the occlusal surface shape or increasing the vertical dimension of the occlusion for full-mouth oral rehabilitation instead of using aggressive treatments like full-crown restorations; and preserving the vitality of the pulp and minimizing invasive intervention on cracked teeth (Fan et al., 2021; Ferraris, 2017).

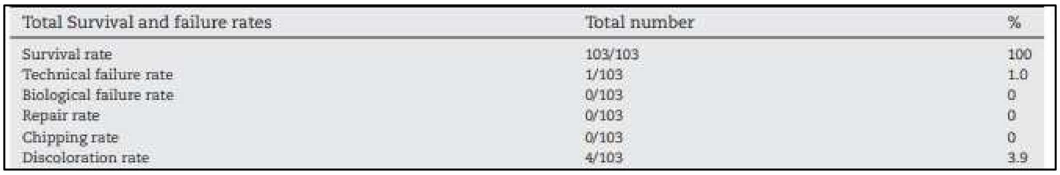
In 2017 Ferraris proposed classifying the different limits of onlay and overlay preparations. He distinguishes three (Figure 19): the butt joint preparation (strict horizontal limit), the bevelled preparation, and the overlay preparation (shoulder preparation) (Ferraris, 2017; Adrien & Emmanuel, 2020).

Figure 19: Illustration of the three possible preparation limits for onlays and overlays (Adapted from Adrien & Emmanuel, 2020).

Overlays are a stable and safer way to achieve physiological occlusion. However, they are more expensive than other restorative approaches that may also provide better control over the optimal form and esthetics over time. The term "occlusal onlays" specifically refers to the lifting of the VDO, which redefines the occlusal relations. Unfortunately, there is a lack of long-term clinical data on occlusal onlays in patients with an increased VDO (Edelhoff et al., 2019).

Ceramic overlay restorations are a reliable and long-lasting solution for dental issues, with a survival rate exceeding 90% which is comparable to conventional full-coverage crowns. Although the most common failure pattern is the fracture of the ceramic and/or the tooth 76.2%, this is still a small percentage compared to the overall success rate. Therefore, if you require a dental restoration that is long-lasting, safe, and effective, ceramic overlay restorations could be an excellent choice to restore posterior teeth (Flores et al., 2022).

The survival rate of monolithic lithium disilicate overlay was 100%. The figure 20 shows important results, including survival and failure rates (Edelhoff et al., 2019).



Total Survival and failure rates	Total number	%
Survival rate	103/103	100
Technical failure rate	1/103	1.0
Biological failure rate	0/103	0
Repair rate	0/103	0
Chipping rate	0/103	0
Discoloration rate	4/103	3.9

Figure 20: Monolithic lithium disilicate occlusal overlay: total survival and failure rates (Adapted from Edelhoff et al., 2019).

Two types of overlay preparation designs have been described in the literature. The first one is a standard full coverage and non-retentive preparation that is guided by the anatomy of the occlusal surface. It also provides adequate interocclusal clearance according to the restorative material used. The second one is a no-preparation (table-top) or minimally invasive design that is recommended for teeth with severe loss of dental tissue caused by occlusal wear (Gierthmuehlen et al., 2023; Sultan et al., 2021).

In 2016, Etienne introduced a novel classification system for overlays, categorizing them based on residual support and the thickness of the restorative material. The classification of overlays is outlined as follows (Figure 21): Type I, or "table-top," comprises a thin layer 1.5 mm predominantly bonded onto enamel. Type II, the most prevalent, ranges from 1.5 mm to 4 mm in thickness and is primarily bonded onto dentin. Type III closely resembles Type II but incorporates a reconstituted core with a dentin substitute. Type IV is specifically designed for endodontically treated teeth.

Each type of overlay serves a distinct clinical purpose and necessitates specific procedures concerning materials and bonding techniques (Étienne & Watzki, 2017).

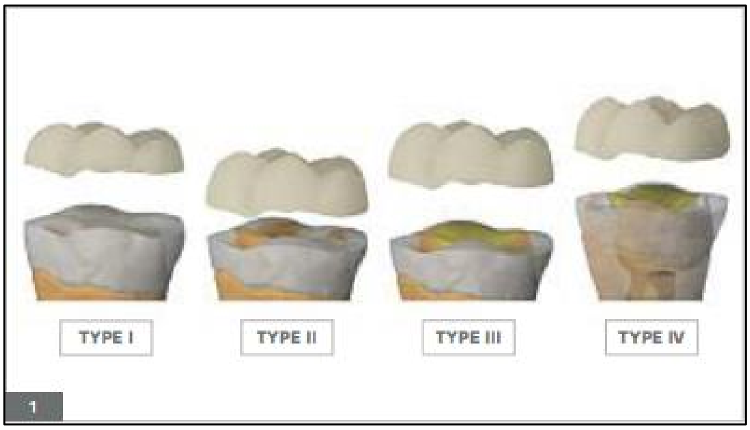


Figure 21: Overlay classification (Adapted from Étienne & Watzki, 2017).

2.1.4. Veneerlays

Veneerlays are a type of dental restoration that combines onlay and buccal veneer techniques. The term was initially used by Edward McLaren et al., who fabricated a monolithic structure using lithium disilicate to restore the upper bicuspid teeth (A. McLaren et al., 2015). Veneerlays are mostly indicated to treat damaged posterior teeth that involve both buccal and occlusal surfaces, as well as for patients with occlusal wear in the posterior teeth (Sultan et al., 2021). According to McLaren et al., the benefits of veneerlays over full crowns include less invasiveness, less technique sensitivity, and more repairability (A. McLaren et al., 2015).

2.1.5. Endocrown

Endocrowns are bonded monolithic ceramic restorations, recommended for the treatment of severely damaged molars demanding endodontic restoration (Elagra, 2019). To meet the criteria, certain preparatory procedures that largely focus on biomechanics are necessary. The cervical edge is shaped like a butt joint, and the preparation of the pulp chamber does not reach into the root canals (Fages, 2013). This efficient and simple concept is in line with the philosophy of bio-integrated prostheses. The restoration can be prepared by computer-assisted machining or by pressing ceramic materials (Hu et al., 2024). New-generation ceramics and adhesives open up the possibility of using this restorative technique as an alternative to typical root-anchored restorations. The special preparation technique and adhesive bonding enable a particularly biomechanically advantageous reconstruction to be achieved (Wicaksono et al., 2023).

<u>Preparation criteria for endocrown :</u>

The objective of occlusal preparation is to reduce a minimum of 2 mm the occlusal surface's height in the axial direction. The reduction can be accomplished by creating 2-mm-deep grooves as guides, followed by using a green diamond wheel bur to further reduce the occlusal surface (Elagra, 2019). The cervical margin is ideally positioned supra-gingivally; however, if dictated by clinical or aesthetic factors, it can be adapted to follow the gingival margin. In order to avoid a staircase effect, any differences in level between various parts of the cervical margin should be connected by a slope that is not higher than 60°. Enamel walls thinner than 2 mm should be eliminated to ensure adequate strength (Fages, 2013).

To confirm stress resistance along the long axis of the tooth, the preparation should be parallel to the occlusal surface (Elagra, 2019).

In axial preparation, the focus is on eliminating undercuts in the access cavity. a green diamond bur whose shape is cylindrical-conical and has a 7° total occlusal convergence is employed to create a seamless transition between the endodontic access cavity and the coronal pulp chamber (Jalali et al., 2023). The preparation is conducted with the bur oriented along the tooth's long axis, applying gentle pressure, and avoiding contact with the pulpal floor to prevent tissue removal. Excessive thinning of pulp chamber walls should be avoided, as it can compromise their thickness and the enamel strip's width

(Figure 22). The depth of the cavity should be a minimum of 3 mm for optimal results (Fages, 2013).

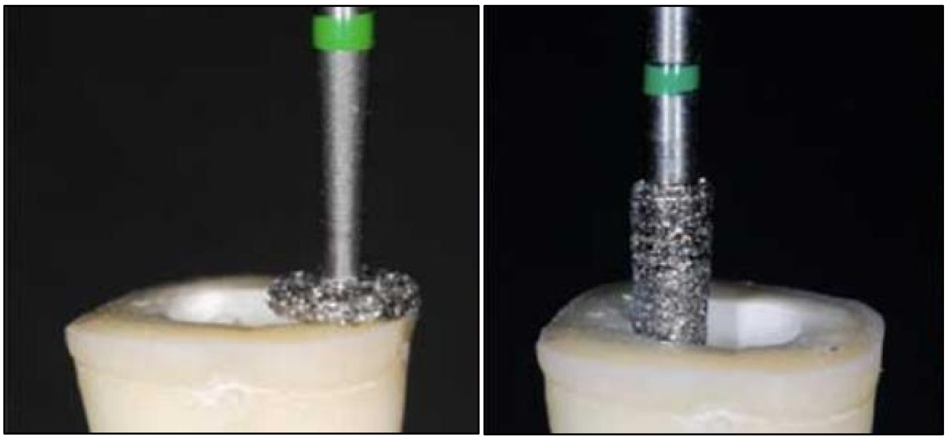


Figure 22: (1) Preparation of the cervical margin (2) Axial preparation with a cylindro-conical burr (Adapted from Fages, 2013).

A clinical study by Bindl et al. found that the rate of bond failure in molars restored with an endo-crown was lower than in premolars, likely due to the larger bonding area in molars (Bindl et al., 2005). Additionally, recent research has shown that endo-crowns placed on molars have a good survivability rate and are less likely to experience debonding (Wicaksono et al., 2023).

Fracture resistance tests conducted on both endo-crown designs (Figure 23) revealed that they substantially surpassed the maximum expected masticatory forces. However, endo-crowns featuring a ferrule design exhibited notably higher fracture resistance when compared to those with a butt joint preparation design (Elagra, 2019). Despite the increased durability seen in ferrule-designed endo-crowns, they exhibited a greater vulnerability to catastrophic failure modes. However, such failures occurred only under loads exceeding typical masticatory forces. In contrast, endo-crowns with a butt joint design predominantly experienced repairable modes of failure when subjected to loads beyond normal masticatory forces (Magdy et al., 2023).

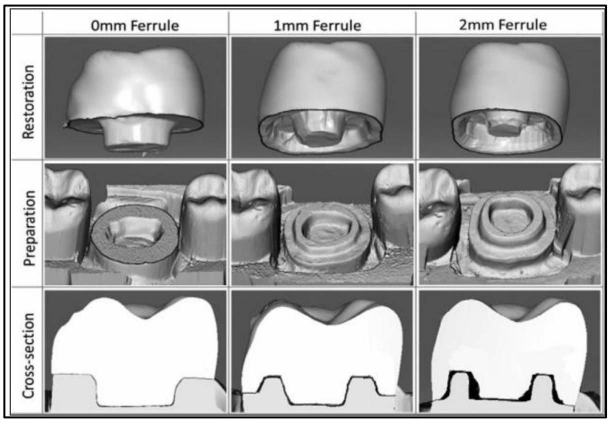


Figure 23: Preparations design : no ferrule, 1 mm ferrule, 2 mm ferrule (Adapted from Elagra, 2019).

2.2. Guidelines preparations for ceramic indirect restoration

To ensure the success of indirect posterior adhesive restorations, meticulous adherence to preparation guidelines is crucial. These guidelines are essential for achieving an accurate fit, maintaining strength, and ensuring long-term durability of the restoration (Figure 24). Here are some key considerations to keep in mind:

a- Round off ridges and angles

It is essential to round off all sharp points and ridges to reduce stresses within the ceramic. This applies to the junction between the occlusal isthmus and the proximal box and the transition between the lateral walls and the occlusal or proximal floor (Hajtó.J, 2013).

b- Minimum thicknesses:

The current recommendations suggest minimum thickness values for various types of restorations. For partial crowns and single crowns, there should be 1.5 mm of ceramic at the occlusal surface and 1 mm at the peripheral edges. For inlays and onlays with reduced preparations ("Table Tops"), a minimum thickness of 1 mm of ceramic is necessary for lithium disilicate and all other glass ceramics 1.5-2 mm. A minimum thickness of 0.3 mm can be considered for occlusal surface supplements with preparation ("Table Tops"), but this should be done with caution due to limited clinical experience (Hajtó.J, 2013).

c- Preparation shapes:

Initially, the occlusal divergence of the sidewalls should be 6 to 10°. The outer limits of the preparations should be clean and orthogonal to the tooth surface to avoid fragile ceramic margins (D'Incau & Zunzarren, 2014).

When preparing a tooth for a restoration, it's important to avoid placing contacts at the margin of the preparation. Additionally, contacts should not be made with any residual surfaces that may break during chewing. There should be enough space between the tooth and its adjacents both horizontally and vertically (Edelhoff & Sorensen, 2002; Stawarczyk B, 2017).

Proximal boxes can be difficult for the dentist to inspect due to their shape and the size of the instruments used. In these areas, using appropriately shaped sonic inserts can help the dentist to prepare the axial and horizontal walls of the boxes correctly (Hajtó.J, 2013).

Fragile cusps should be reduced by at least 1 mm, and the minimum thickness of ceramic should be maintained, particularly in occlusal grooves that are subjected to occlusal forces. A consistent shade transition from the tooth to the restoration can be achieved by creating a small fillet at the outer margins. This will also increase the surface area of the prepared enamel prisms, improving adhesive bonding (Adrien & Emmanuel, 2020).

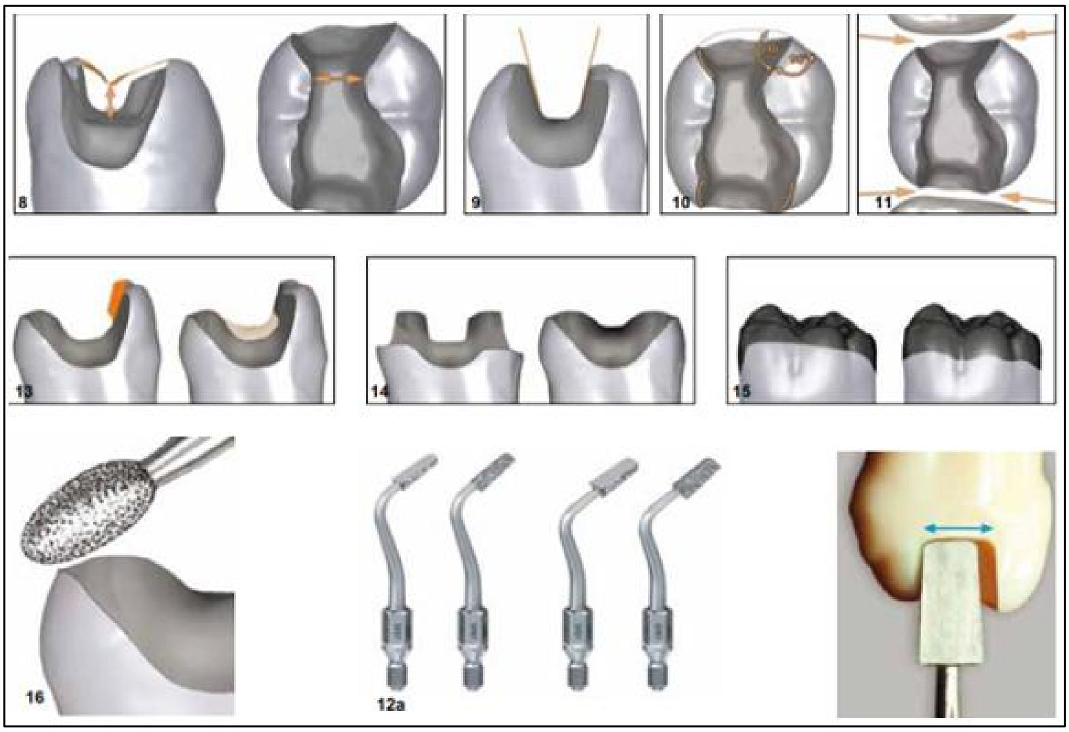


Figure 24: Guidelines preparations for ceramic indirect restoration (Adapted from Hajtó.J, 2013).

2.3. Factors that affect the success of Posterior Indirect Adhesive Restoration (PIAR)

Achieving successful restoration depends on several key factors. Understanding and addressing these factors can significantly improve the outcome of the restoration process (Ferraris, 2017).

2.3.1. Materials

For adhesive dentistery, there are many types of materials used for making partial restorations in posterior teeth using different techniques such direct technique, semi-direct (intraoral and extraoral) and indirect. To decide which materials and techniques to use, we should consider both of general and local criteria. General parameters include the patient's age, motivation, oral hygiene, caries risk assessment, dietary habits, functional activity, financial resources, and ergonomics. Meanwhile, local parameters include cavity shape, the position of the tooth, the thickness of remaining walls, the position of cervical margins, the presence of cracks, the presence of cervical lesions, the evaluation of the element in pre-prosthetic function, and the presence of periodontal lesions or pulp disease (Veneziani, 2017).

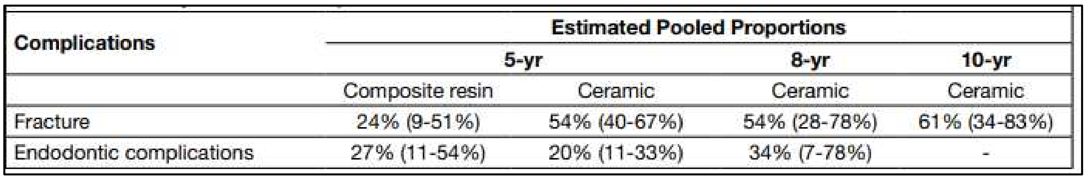
A- Feldspathic Porcelain versus Glass Ceramic

Glass ceramic has a higher flexural strength than feldspathic porcelain, indicating that restorations made with glass ceramic may have a lower failure rate. However, a study found that the cumulative survival rate of feldspathic porcelain inlays was 90%, while for glass ceramic it was 86%. Another study reported that glass ceramic restorations had a low survival rate due to severe discoloration (Fan et al., 2021).

B- Composite resin

According to a review, the 5-year cumulative survival rate of composite resin inlays, onlays and overlays is excellent, at 91%. Pallesen & Qvist found that after 11 years of service, 88% of composite resin inlays still functioned (Pallesen & Qvist, 2003) well. Barabanti and others also reported that around 90% of indirect composite resin inlays and onlays used for restoring large tooth defects were still effective after 10 years of clinical service (Barabanti et al., 2015). A more recent study by Derchi and colleagues found that the composite resin inlays had a failure rate of 12% after 12 years (Derchi et al., 2019).

Significant differences were found according to the type of material used for restoration (Figure 25). The survival rate of composite material was lower (90%) when compared to other materials such as hybrids and disilicate (99% and 98%, respectively). Due to their superior clinical performance, hybrid materials and ceramics should still be considered as the preferred options for indirect partial restorations in the posterior teeth (Bustamante-Hernández et al., 2020; Fan et al., 2021).



Complications	**Estimated Pooled Proportions**			
	5-yr		**8-yr**	**10-yr**
	Composite resin	Ceramic	Ceramic	Ceramic
Fracture	24% (9-51%)	54% (40-67%)	54% (28-78%)	61% (34-83%)
Endodontic complications	27% (11-54%)	20% (11-33%)	34% (7-78%)	-

Figure 25: Summary of data of complications (Adapted from Fan et al., 2021).

2.3.2. Tooth preparation and stronger materials

Fractures are a common complication in ceramic restorations with a pooled proportion of 54% at 5 years, 54% at 8 years and 61% at 10 years. This indicates that the harder tooth structure is lost due to cavity preparation, the stronger material is needed. To withstand the mastication force in posterior teeth, it is suggested that the thickness of ceramics should be at least 1.5 to 2 mm for functional cusps and 1-1.5 mm for non-functional cusps (Fan et al., 2021).

2.3.3. Vital teeth Versus nonvital teeth

Several studies have indicated that posterior indirect adhesive restorations in nonvital teeth have demonstrated commendable clinical performance after a period of 2-4 years. However, previous research has suggested that vital teeth display a more avantageous outcome and are not as likely to fail as nonvital teeth. After 3 years of employing IPS Empress onlays and partial coverage restorations, 85.7% of failures occurred in the restorations of nonvital teeth (Fan et al., 2021).

2.3.4. Molar Versus premolar

Several previous studies have shown a significantly higher rate of failure of restorations in molars than in premolars. However, Collares et al. reported that no differences in success and survival rates were found between inlays and onlays or between molars and premolars after analysing 5791 ceramic inlays and onlays (Collares et al., 2016).

2.3.5. Parafunctional habits

Studies have shown that composite resin and ceramic inlay and onlay restorations are more likely to fracture in individuals with parafunctional habits such as teeth grinding or clenching. This may be due to the additional stress placed on the materials over time, leading to fatigue and eventual fracture. However, some researchers argue that there is no direct evidence linking parafunctional habits with the fracture of these types of restorations (Fan et al., 2021).

2.4. Clinical steps

The table below summarizes the preparation steps for posterior indirect adhesive restorations (Table 4).

Table 4: Summary of preparation steps for posterior indirect adhesive restorations (Adrien & Emmanuel, 2020).

1	**Biomechanical analysis of the tooth** Assessment of occlusal context and mechanical stress
2	**Choice of shade**
3	**Tooth isolation.** Preferably at the beginning of the session to facilitate placement and improve visibility
4	**Removal of old restoration and carious tissue**
5	**Assessment of remaining tissue** Removal of unsupported enamel and walls smaller than 2 mm
6	**Occlusal reduction according to material**
7	**Removal of cracks and fissures And Immediate dentin seal (IDS)**
8	**Composite cavity preparation (CDO)** If required undercut filling, simplified cavity geometry
9	**Finishing**
10	**Checks before and after dam removal**

3. BONDING

3.1. Fundamental concepts of enamel and dentin adhesion

3.1.1. Adhesion definition and mechanism

Definition

Adhesion refers to the attraction between materials, whether similar or dissimilar, resulting from a combination of physical and mechanical processes as well as intermolecular forces (Özcan et al., 2012).

Mechanism

In dentistry, adhesion entails two key aspects: adhesion to the tooth structure and the restorative material. The characteristics of the tooth and the material being utilized influence the adhesion quality. Dental composite resin materials have emerged as cost-effective and minimally invasive alternatives to other restorative materials, and their direct intraoral applications have become routine (Katta et al., 2016).

However, a dilemma persists within the dental profession regarding the choice between dental ceramics including feldspathic, glass, and oxide ceramics and polymeric materials for minimally invasive applications. To better understand the surface reactions between current bonding systems and dental hard tissues and current bonding systems, it is beneficial to discuss tooth substrates briefly (Özcan et al., 2012).

3.1.2. Dental adhesion

3.1.2.1. Adhesion to enamel

Enamel, the outer layer covering the crown of a tooth, is a remarkable tissue that plays a crucial role in protecting the underlying dentin and pulp. It is unique in its composition and structure, making it the hardest and most mineralized substance in the human body (Perdigão et al., 2019).

Compositionally, enamel is predominantly composed of inorganic hydroxyapatite crystallites, which account for about 96% of its weight. Hydroxyapatite has the chemical formula [Ca10(PO4)6(OH)2] and is a complex calcium phosphate compound (Abad-Coronel et al., 2019). This high concentration of hydroxyapatite gives enamel its exceptional hardness and resistance to wear and decay (Bedran-Russo et al., 2017).

Enamel not only consists of hydroxyapatite, but also contains a small amount of organic material, primarily proteins such as collagens, which make up about 1% of its composition (Figure 26). These proteins contribute to the structural integrity of enamel and play a role in its formation and maintenance (Özcan et al., 2012).

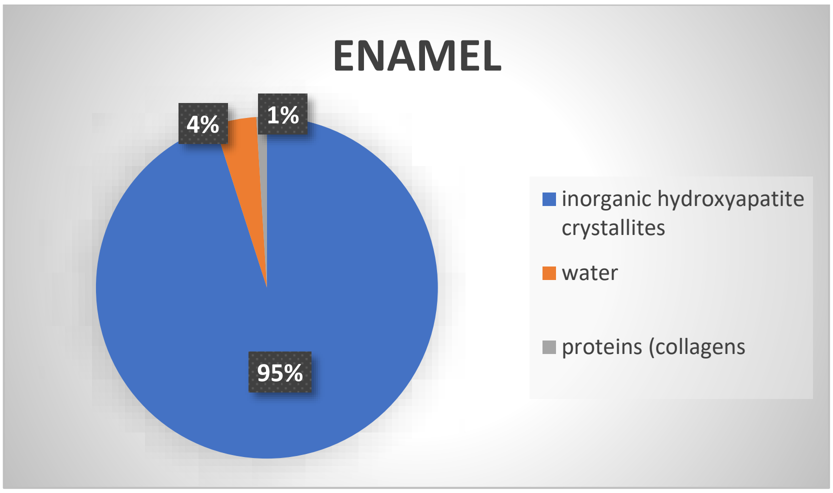


Figure 26: Enamel composition.

Structurally, enamel is organized into tightly packed structures known as enamel rods or enamel prisms. These rods are arranged in a highly ordered pattern, running perpendicular to the surface of the tooth. Each enamel rod consists of tightly packed hydroxyapatite crystals aligned along its length, providing strength and rigidity to the enamel structure (Özcan et al., 2012).

The arrangement of enamel rods in different regions of the tooth varies slightly and creates characteristic patterns, such as Hunter-Schreger bands. In order to achieve micromechanical adhesion, the surface enamel layer needs to be demineralized (Perdigão et al., 2021). The gold standard for this procedure is the multi-step etch and rinse technique, which utilizes highly concentrated phosphoric acid (35-37%, pH=1.0) (Van Meerbeek & Others, 2003). By selectively dissolving enamel rods, acid etching provides micro-roughness on the surface, which increases surface energy and is crucial for micromechanical adhesion (Figure 27). Acid-etching is a process that changes the smooth enamel surface into an irregular surface, which increases its surface free energy (Perdigão et al., 2019).

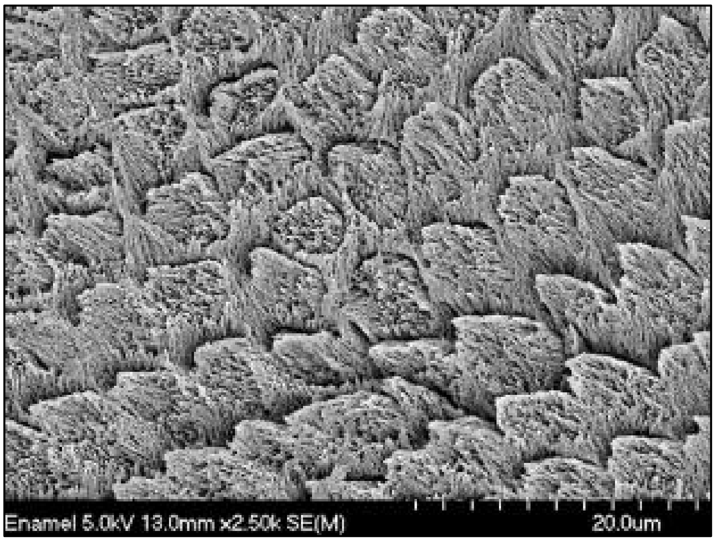


Figure 27: Scanning electron micrograph (SEM) of enamel etched with 35% phosphoric acid for 15 seconds (Adapted from Perdigão et al., 2019).

When a fluid resin-based material is applied to the irregularity created by acid-etching, the resin penetrates the surface with the help of capillary action. The monomers in the material polymerize and become interlocked with the enamel surface, forming resin microtags within the enamel surface. These microtags are responsible for the strong adhesion between the resin and enamel (Perdigão et al., 2019).

Enamel etching produces three distinct micro-morphologic patterns (Figure 28). The Type I pattern entails selectively dissolving the cores of the prisms while leaving the peripheries intact. The type II etching pattern is characterized by the dissolution of the outer enamel while the cores remain intact, in contrast to type I. Type III etching exhibits a less conspicuous appearance compared to the other two patterns. It encompasses regions that mimic the other patterns, as well as regions that do not have any relationship to the morphology of enamel prisms (Perdigão et al., 2019).

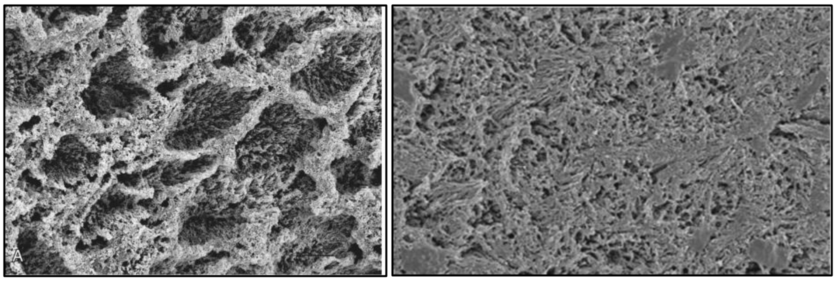


Figure 28: SEM of enamel etched with 35% phosphoric acid for 15 seconds, denoting (1) type I etching pattern. (2) type III etching pattern (Adapted from Perdigão et al., 2019).

3.1.2.2. Adhesion to dentin

Dentin is a vital tissue found in teeth, which shares many physical and chemical properties with bone. It is made up of approximately 70% mineral content, mostly hydroxyapatite crystals, and around 20% organic content (Bedran-Russo et al., 2017). The organic phase mostly consists of collagen, and the remaining 10% is water. During the formation of dentin, water gets trapped within collagen fibers, bonding to hydroxyproline ends in these fibers (Figure 29) (Abad-Coronel et al., 2019; Özcan et al., 2012).

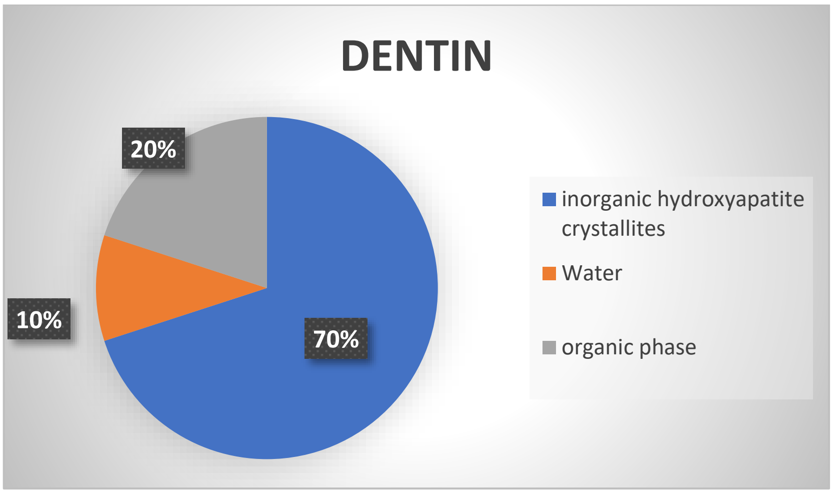


Figure 29: Dentin composition.

Dentin consists of microscopic channels called dentinal tubules that are formed through the mineralization and deposition of a predentin matrix. These tubules make dentin permeable. Intertubular dentin lies between the tubules and contains densely packed collagen fibrils ranging from 50 to 200 nm in diameter, surrounded by hydroxyapatite mineral. Peritubular dentin, which covers the tubules, is more mineralized than intertubular dentin and contains less collagen (Van Meerbeek & Others, 2003).

Type I collagen is the predominant collagen type found in both bone and dentin. It makes up approximately 90% of the total protein content in the organic matrix. This collagen type is the most abundant in the human body and plays a crucial role in providing structural integrity and support to both bone and dentin tissues (Bedran-Russo et al., 2017; Özcan et al., 2012).

In the 1980s and 1990s, new adhesive techniques were introduced which challenged the classic concepts of operative dentistry. These techniques were first used for enamel and later for dentin. However, attaining adherence to dentin continues to pose challenges.

Adhesive compounds may interact with dentin by mechanical, chemical, or combined mechanisms (Perdigão et al., 2019). The significance of micromechanical bonding, akin to the process observed in enamel bonding, has finally been acknowledged. The adherence of dentin is mostly dependent on the infiltration of adhesive monomers into the collagen fiber network that is revealed by acid etching (Figure 30) (Perdigão et al., 2021).

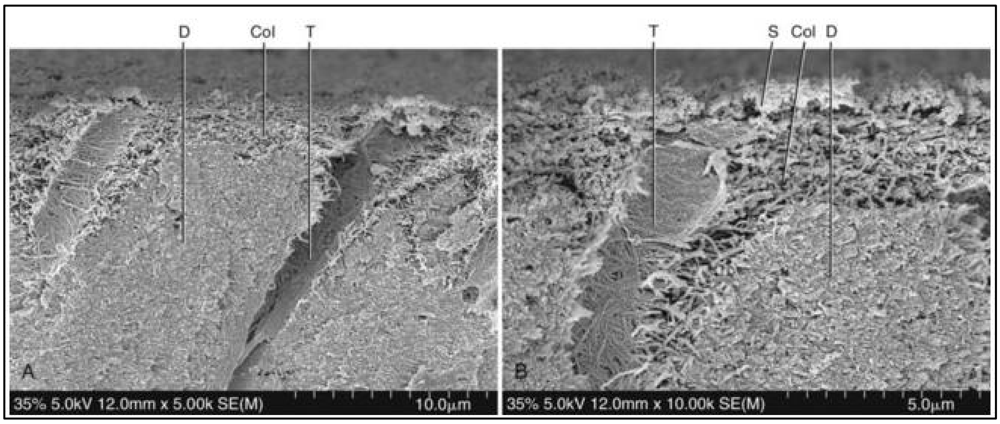


Figure 30: (1) Dentin etched with 35% phosphoric acid, (2) Higher magnification view of etched dentin (Adapted from Perdigão et al., 2019).

Bonding to dentin is much more challenging, multiple variables contribute to the difference in bonding between enamel and dentin. (Katta et al., 2016). Enamel is a densely mineralized substance made up of over 90% hydroxyapatite, while dentin has a significant amount of water and organic material, mostly type I collagen. Dentin is comprised of a compact arrangement of tubules that provide a connection between the pulp and the dentino-enamel junction (DEJ). The tubules are lined by a layer of hypermineralized dentin known as peritubular dentin. In the intertubular dentin with lower mineralization, there are collagen fibrils that exhibit the distinctive collagen banding pattern. Submicron channels pierce the intertubular dentin, enabling the flow of tubular fluids and fibers across adjacent tubules, creating intertubular anastomoses (Figure 31) (Perdigão et al., 2019).

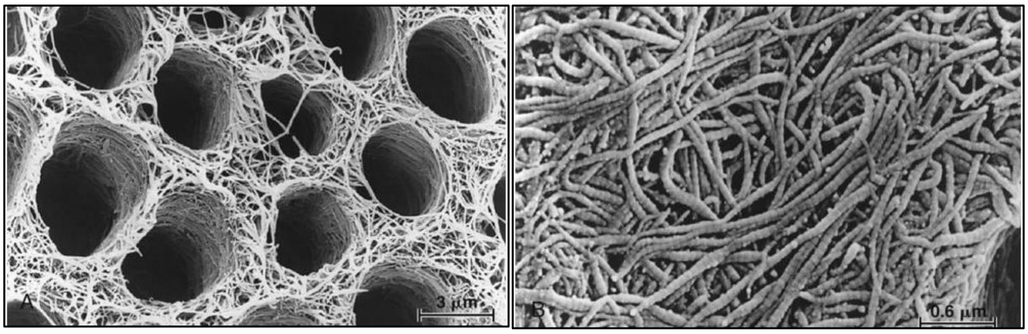


Figure 31: (1) Scanning electron micrograph of etched dentin showing exposed collagen fibers. (2) Higher magnification shows the characteristic collagen banding in intertubular collagen. Superficial (Adapted from Perdigão et al., 2019).

The adhesion of synthetic resin to the tooth substrate involves a two-phase exchange process. In the first phase, calcium phosphates are removed from the tooth surface, exposing microporosities present in both enamel and dentin (Perdigão et al., 2021).

While micro-mechanical interlocking is crucial for achieving strong bonding in clinical applications, there is a growing interest in exploring the potential benefits of additional chemical interaction between functional monomers present in the resin and tooth substrate components. This chemical interaction could enhance the adhesive bond strength and durability, providing potential advantages in clinical practice (Van Meerbeek & Others, 2003).

3.2. Classification of Adhesive Systems

There have been several categories of adhesive systems (Figure 32). Through successive generations, varying in terms of the number of clinical steps and the modalities of action employed (Abad-Coronel et al., 2019).

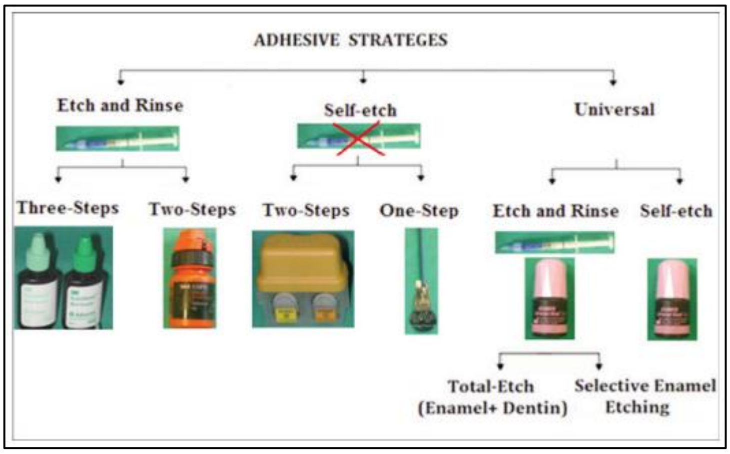


Figure 32: Modern adhesive strategies (Sofan et al., 2017).

3.2.1. Etch and Rinse Adhesive Systems

There are at least three phases in this adhesion method (Vincent et al., 2022). Firstly, using a conditioner or acid etchant; secondly, using a primer or adhesion enhancing agent; and lastly, applying the bonding agent or adhesive resin. However, a simplified version combines the second and third steps, but still follows a separate "etch and rinse" phase (Perdigão et al., 2021).

This technique only requires two steps (Figure 33). The first step involves the selective dissolution of hydroxyapatite crystals through etching, commonly with a 30-40% phosphoric-acid gel. The second step involves the in situ polymerization of resin that is readily absorbed by capillary attraction within the created etch pits, thereby enveloping individually exposed hydroxyapatite crystals (Abad-Coronel et al., 2019; Perdigão et al., 2019).

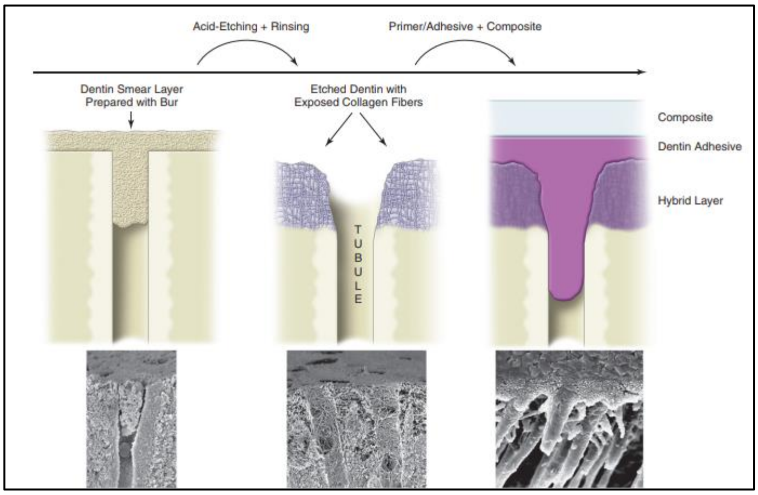


Figure 33: Bonding of resin to dentin using an etch and rinse technique (Adapted from Perdigão et al., 2019).

During the dentin process, the application of phosphoric acid reveals a microscopically porous structure of collagen that is almost completely lacking hydroxyapatite (Figure 34). The main bonding process of etch and rinse adhesives to dentin is predominantly diffusion-based and relies on the resin infiltrating and bonding with the collagen fibril scaffold. It is important for this penetration to be as thorough as feasible (Abad-Coronel et al., 2019).

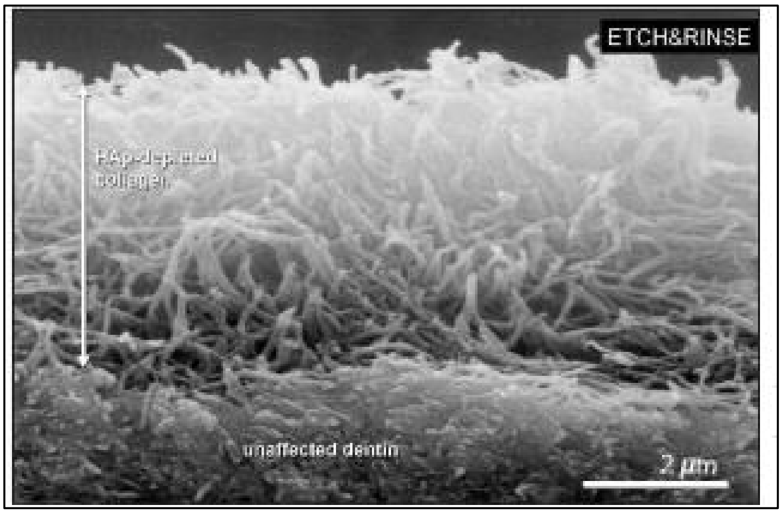


Figure 34: Fe-SEM photomicrograph of dentin etched for 15 seconds with 35% phosphoric acid (Ultra-Etch, Ultradent) (Adapted from Van Meerbeek & Others, 2003).

3.2.2. Self-Etch Adhesives

The self-etch technique in dentistry offers a promising approach due to its user-friendly nature and reduced technique sensitivity. Unlike traditional methods, it eliminates the need for a separate etching step, streamlining the process and reducing the risk of application errors (Vincent et al., 2022).

However, the long-term effects of incorporating dissolved hydroxyapatite crystals and residual smear layer remnants within the bond are not fully understood. Excess primer/adhesive solvent within the interfacial structure may weaken bond integrity and contribute to nanoleakage or hinder monomer polymerization. Furthermore, the resulting hydrophilic interfacial structure is prone to hydrolytic degradation (Abad-Coronel et al., 2019).

Self-etch adhesives can be classified as strong ($pH < 1$), intermediary strong ($pH = 1\text{-}2$), mild ($pH \approx 2$) and ultra-mild ($pH > 2.5$) self-etch adhesives. The "Mild" self-etch adhesives, which combine chemical bonding and micromechanical interlocking, offered the best bonding performance to dentin (Figure 35) (Vincent et al., 2022).

The self-etch approach can be two-step or one-step. Strong self-etch adhesives primarily rely on diffusion-based bonding mechanisms, while mild self-etch systems create a superficial demineralization layer for micromechanical interlocking through hybridization.

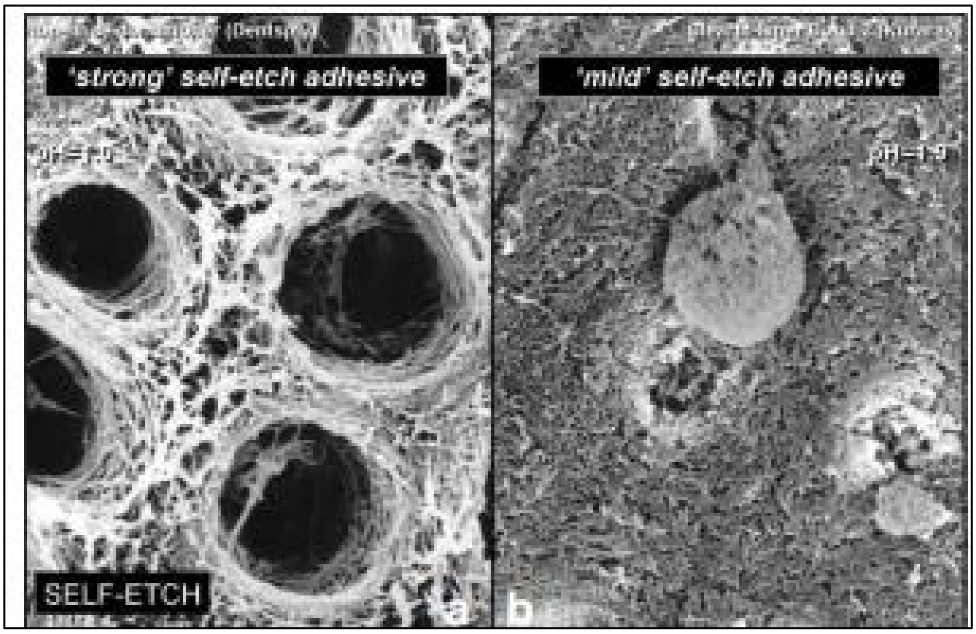


Figure 35: Fe-SEM photomicrographs of dentin either treated by strong and mild self-etch adhesive (Adapted from Van Meerbeek & Others, 2003).

Although mild self-etch adhesives show promise, their weakest property is their bonding potential to enamel or the strong self-etch adhesives offer a balance between demineralization depth and bonding effectiveness. Further research is needed to evaluate the long-term stability and effectiveness of self-etch approaches (Van Meerbeek & Others, 2003).

Several variables influence the permeability of dentin. In addition to vasoconstrictors, which reduce pulpal pressure and fluid flow in the tubules, additional factors such as the size and length of the tubules, viscosity of dentin fluid, pressure difference, size of dissolved substances in the tubular fluid, and the rate at which substances are removed by the blood vessels in the pulp also contribute to permeability (Figure 36). All of these variables make dentin a dynamic substrate, and, as a result, it is a challenging substrate to bond with (Katta et al., 2016).

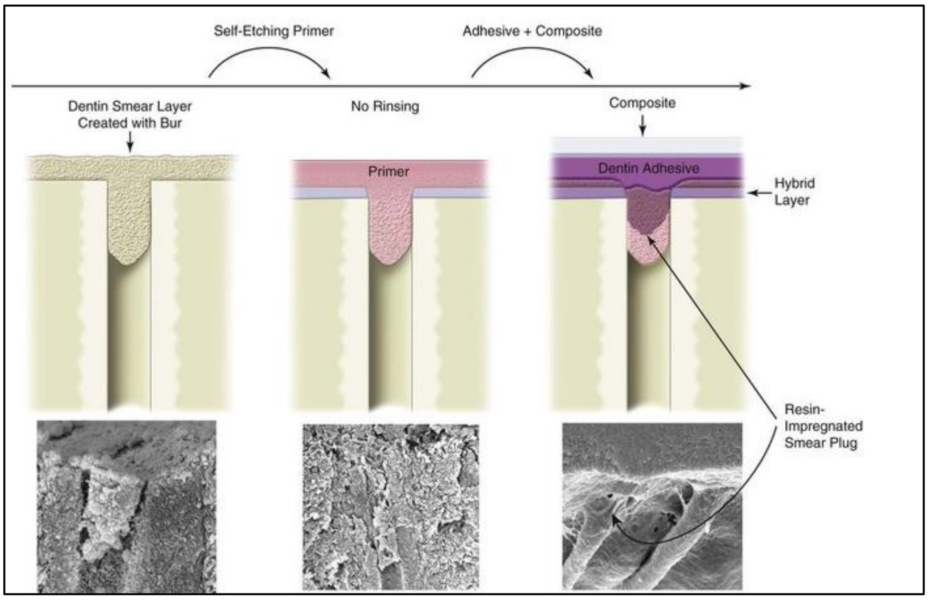


Figure 36: Bonding to dentin using a self-etch primer
(Adapted from Perdigão et al., 2019).

3.2.3. Universal adhesives

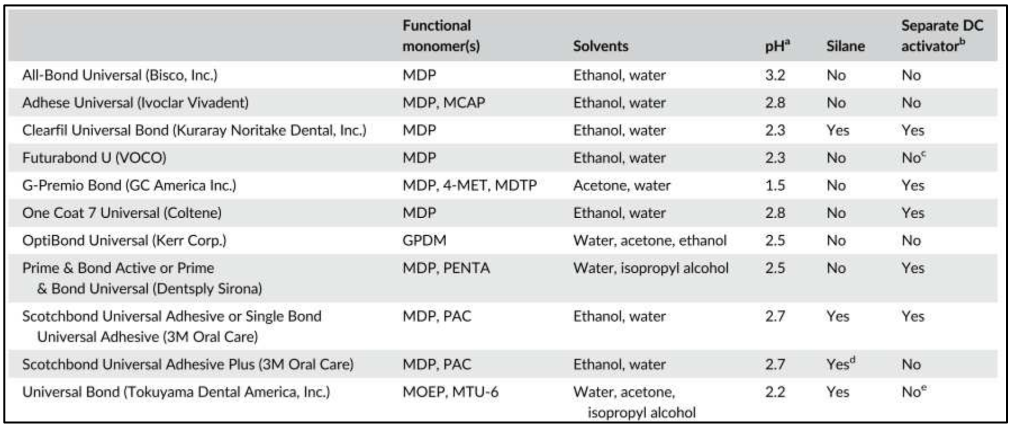
There are new dental adhesives available that come in one bottle. These are called One step Self-Etch Adhesives (1-SEAs) and are easy to use. However, there is still some difference in professional opinion about which adhesive strategy to use and how many steps are necessary. These new dental adhesives are known as "universal" or "multi-mode" adhesives, which means they can be used for various clinical applications (Sato et al., 2021). Some adhesives are called "universal adhesive" because they have a wide range of clinical applications not just for direct restorations but also for indirect restorations, resin coating, core buildups, zirconia primer, and tooth desensitizer (Perdigão et al., 2021).

Universal adhesives, regardless of whether they are applied as self-etch or etch-and-rinse adhesives, show evidence of deterioration in the bonding between different surfaces after being stored in water for 12 months. Nevertheless, the use of the self-etch technique leads to a reduction in nanoleakage. Although the bonding technique has been simplified, universal adhesives are expected to have the same deterioration pattern as prior one-step self-etch adhesives (Perdigão et al., 2019).

There was no significant statistical difference observed across the various adhesion techniques. Nevertheless, Scotchbond Universal (SBU) exhibited more marginal staining and marginal degradation in SE mode compared to E&R and selective enamel etch modes (Perdigão et al., 2021).

Universal adhesives containing the monomer 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) have shown satisfactory results in dentistry (Figure 37). This acidic monomer allows for self-etching application, usable on enamel and dentin. In addition to 10-MDP, other types of functional monomers (phosphate, phosphonate, carboxylic) are available on the market. These monomers are the main active components of self-etching adhesives, conditioning and preparing the dental substrate while initiating the diffusion of comonomers (Gealh et al., 2023).

Studies have confirmed that the modified 10-MDP monomer is the best acid. Furthermore, adhesives containing the 10-MDP monomer are less hydrophilic due to their long molecular chain. This reduces water absorption and enhances the interaction between 10-MDP and hydroxyapatite, forming nanolayers and increasing adhesion. The 10-MDP monomer forms a stable layer by depositing MDP-Ca salts on the adhesive interface, which increases mechanical resistance and establishes a very strong and stable chemical interaction with hydroxyapatite. The formation of water-insoluble MDP-Ca salts protects the collagen fibers in dentin. The intense chemical interaction between the 10-MDP monomer and hydroxyapatite is due to the superficial dissolution of hydroxyapatite induced by 10-MDP adsorption, followed by the deposition of less soluble MDP-Ca salts compared to salts produced by other monomers (Gealh et al., 2023; Perdigão et al., 2021).



	Functional monomer(s)	Solvents	pH[a]	Silane	Separate DC activator[b]
All-Bond Universal (Bisco, Inc.)	MDP	Ethanol, water	3.2	No	No
Adhese Universal (Ivoclar Vivadent)	MDP, MCAP	Ethanol, water	2.8	No	No
Clearfil Universal Bond (Kuraray Noritake Dental, Inc.)	MDP	Ethanol, water	2.3	Yes	Yes
Futurabond U (VOCO)	MDP	Ethanol, water	2.3	No	No[c]
G-Premio Bond (GC America Inc.)	MDP, 4-MET, MDTP	Acetone, water	1.5	No	Yes
One Coat 7 Universal (Coltene)	MDP	Ethanol, water	2.8	No	Yes
OptiBond Universal (Kerr Corp.)	GPDM	Water, acetone, ethanol	2.5	No	No
Prime & Bond Active or Prime & Bond Universal (Dentsply Sirona)	MDP, PENTA	Water, isopropyl alcohol	2.5	No	Yes
Scotchbond Universal Adhesive or Single Bond Universal Adhesive (3M Oral Care)	MDP, PAC	Ethanol, water	2.7	Yes	Yes
Scotchbond Universal Adhesive Plus (3M Oral Care)	MDP, PAC	Ethanol, water	2.7	Yes[d]	No
Universal Bond (Tokuyama Dental America, Inc.)	MOEP, MTU-6	Water, acetone, isopropyl alcohol	2.2	Yes	No[e]

Figure 37: Current universal adhesives (Perdigão et al., 2021).

A new type of adhesive, called Scotchbond Universal Plus Adhesive (Figure 38), has been developed by 3M™. It contains two silane molecules in its solution, specifically 3-(aminopropyl) triethoxysilane (APTES) and γ-methacryloxypropyltriethoxysilane (γMPTES). The addition of these silanes has significantly improved the bonding performance of the adhesive to glass-matrix ceramics, compared to its previous version which only contained γ-methacryloxypropyltrimethoxysilane (Perdigão et al., 2021).

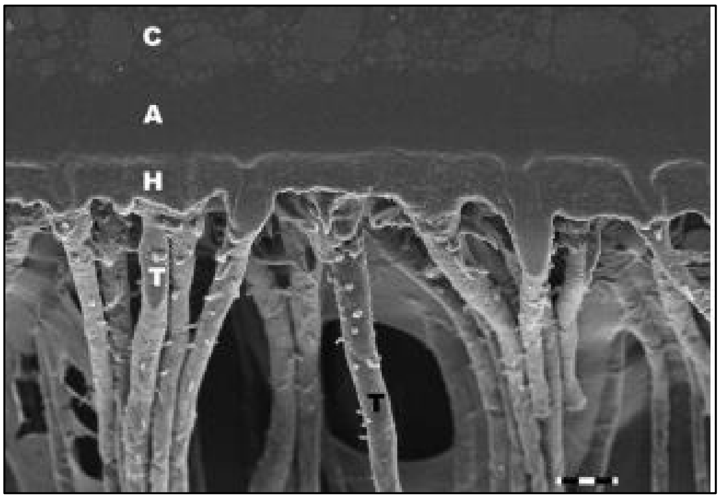
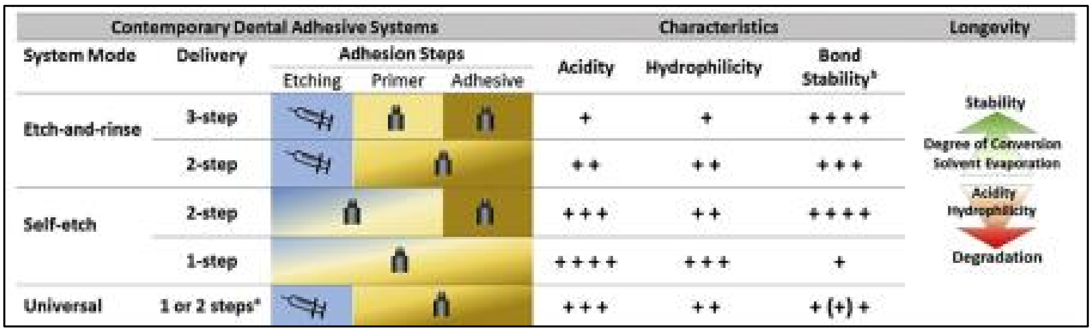


Figure 38: Micrograph of the interface between Scotchbond Universal Plus Adhesive (3M™) and dentin C, Filtek Supreme Ultra Flowable Restorative (3M™); A, Scotchbond Universal Plus Adhesive (3M™); H, hybrid layer ; T, resin tag (Adapted from Perdigão et al., 2021).

The following figure (Figure 39) summarizes contemporary dental adhesives systems and characteristics affecting the longterm stability of dentin–resin interfaces.



Contemporary Dental Adhesive Systems					Characteristics			Longevity
System Mode	Delivery	Adhesion Steps			Acidity	Hydrophilicity	Bond Stability*	
		Etching	Primer	Adhesive				
Etch-and-rinse	3-step				+	+	+ + + +	Stability Degree of Conversion Solvent Evaporation Acidity Hydrophilicity Degradation
	2-step				+ +	+ +	+ + +	
Self-etch	2-step				+ + +	+ +	+ + + +	
	1-step				+ + + +	+ + +	+	
Universal	1 or 2 steps*				+ + +	+ +	+ (+) +	

Figure 39: Current contemporary dental adhesives systems and characteristics affecting the longterm stability of dentin–resin interfaces (Adapted from Bedran-Russo et al., 2017).

4. BONDING PROTOCOL

The bonding procedure is simple in principle, but unfortunately it is complicated by several factors. These factors include the choice of luting cement, the exact clinical technique, and the selection of the best way to mechanically and chemically activate the involved surface before bonding (Amorim et al., 2018). Bonding protocols play a crucial role in ensuring optimal adhesion (Rocca, 2006).

4.1. Prerequisites

4.1.1. Rubber dam isolation

A rubber dam is a tool that is used to isolate the specific area during restorative and endodontic treatment. Despite criticism for being time-consuming and expensive, installing a rubber dam is essential for preserving antisepsis, managing moisture, and shielding patients from toxic materials they may inhale (Falacho et al., 2023). In 1869, Dr. Sanford Christie Barnum developed the use of a thin rubber material for the reason of isolating teeth. Effective tooth isolation is crucial for preventing leakage in both the operation field and the oral cavity. When using a rubber dam before bonding ceramic restorations, medical professionals may encounter difficulties which are a gingival discomfort and/or bleeding (Figure 40). To ensure thorough and efficient bonding of the ceramic restoration, it is necessary to carefully insert the rubber dam and secure it with appropriate clamps on the teeth (Jurado et al., 2021).

Figure 40: Occlusal view after rubber dam isolation (Adapted from Rocca, 2006).

Bond strength values to enamel are significantly impacted by intraoral relative humidity. In the absence of sufficient rubber dam isolation, dental adhesives' performance was compromised, which might have long-term effects on our patients' oral health as well as the longevity of restorations (Figure 41) (Falacho et al., 2023).

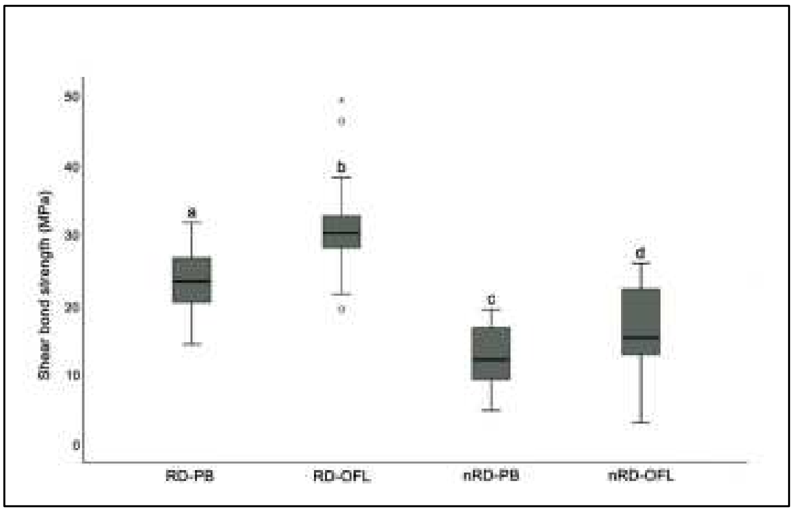


Figure 41: Enamel bond strenghts with and without rubber dam (Adapted from Falacho et al., 2023).

4.1.2. Try-in and shade control

Prior to bonding a restoration, it is important to conduct a try-in to ensure the proper fit, color accuracy, and occlusion. During this process, the restoration's fit integrity and interproximal contacts are assessed (Pilecco et al., 2024).

To determine the final color of a ceramic restorations and select the appropriate shade of resin cement, try-in paste is used as a visual aid. This paste helps achieve a harmonious color match between the restoration and adjacent natural teeth (Alghazali et al., 2018).

Different cleaning protocols like 37% phosphoric acid, air-water spray, or Ivoclean have been evaluated to determine their impact on the mechanical performance of adhesively bonded lithium disilicate restorations. Interestingly, these protocols seem to have minimal effects on the restoration's mechanical performance. Both short-term and long-term assessments have shown no significant differences compared to cleaning a pristine ceramic surface (Pilecco et al., 2024).

However, it is worth noting that air-water spray for cleaning may leave remnants of the try-in paste on the ceramic surface. Despite this, all cleaning methods, except for air-water spray, demonstrated a significant reduction in bond strength following the application of the aging protocol (Pilecco et al., 2024).

After the try-in, it is essential to thoroughly clean the restoration using universal cleaning paste or etchant gel. Effective cleaning is crucial for enhancing the bond strength and providing mechanical reinforcement against potential fatigue (ivoclar vivadent, 2013).

4.2. Dental surface treatment

4.2.1. Air abrasion

It is crucial to thoroughly clean the preparation area and remove any debris before fitting the restorations. If there is any residual provisional material or cement, it can negatively affect the bond strength and make it difficult to trial fit the restorations. To clean the preparation surfaces, it is recommended to use 27 µm aluminum oxide at 40 psi. This method has been proven to effectively clean the surfaces without damaging previously placed dental bonding agents, dentin, or enamel. During the cementation appointment, in case of immediate dentin sealing, the bonded dentin surface can be reactivated using air abrasion (Politano et al., 2018).

4.2.2. Etch the tooth

A 35% phosphoric acid gel with high viscosity is utilized for a technique known as differential etching. This involves applying the etchant primarily to the enamel for 15 seconds initially, followed by another 15-second application to the dentin surface (Politano et al., 2018). This method ensures thorough etching of the enamel while minimizing the risk of over-etching the dentin. To further reduce this risk, immediate dentin sealing is performed during the preparation appointment. Precision timing of each step is crucial, rather than relying on estimations. Finally, the etchant is meticulously rinsed away using an air-water syringe and carefully dried to maintain adequate hydration of the dentin while eliminating any standing moisture (Sato et al., 2021).

4.2.3. Adhesive

Applying the adhesive to the preparation areas. This layer serves as a wetting agent for the resin cement. To prevent inadequate seating due to the film thickness of the cured adhesive layer, it is recommended to wait curing the adhesive until the restoration is entirely placed (Politano et al., 2018).

The following figure (Figure 42) shows the different steps of dental surface treatment before bonding.

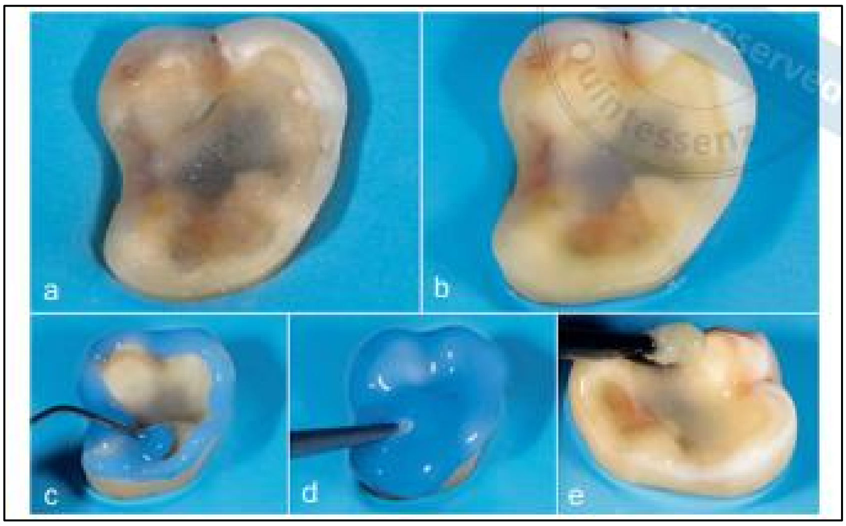


Figure 42: Dental surface treatment (Adapted from Politano et al., 2018).

4.3. Ceramic Surface Treatment

4.3.1. Sandblasting

The first surface treatment applied to ceramics is sandblasting, which exposes a new, pure and active surface layer underneath the top-bonding surface. The surface energy of the new layer decreases when it combines and attracts to other chemical compounds. To create a strong resin bond, it's necessary to have chemical bonding and micromechanical interlocking to the ceramic surface (Amorim et al., 2018). In order to sufficiently activate the surface, this has to be cleaned and roughened. Common ways of treatment include grinding, acid etching, airborne particle abrasion with aluminum oxide, abrasion with diamond rotary tools, or combinations of any of these techniques. Acid etching can be used to produce an appropriate surface roughness and texture using solutions of hydrofluoric acid (HF) or ammonium bifluoride. This method selectively removes the glassy matrix and exposes crystalline structures.

This method of surface treatment involves using around 50 micrometer-diameter aluminum particles, blasted at a pressure of 80 pounds per square inch for 15 seconds (Figure 43). The purpose of this treatment is to create micro-retentions that help to increase the bond strength between cement resins and ceramic restorations. The treatment creates irregularities on the surface of the ceramic, which in turn improves the interaction with the cements (Amorim et al., 2018).

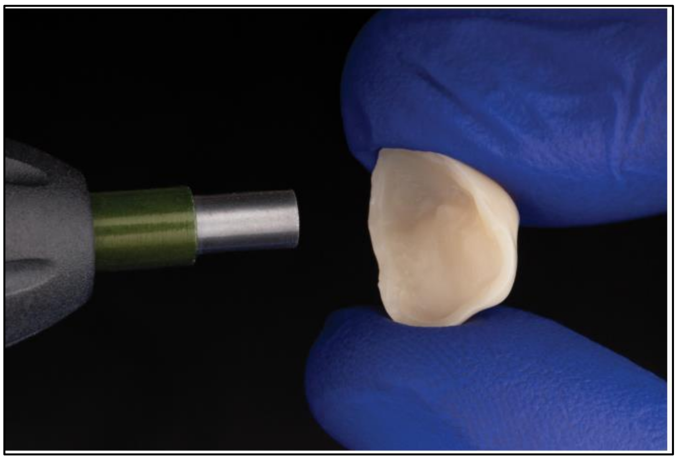


Figure 43: Air-particle abrasion of the internal surface at 2 bar pressure (Adapted from Markus B. Blatz & Amirah Alammar, 2023).

The most specialized surface treatment technique in dentistry is CoJet air abrasion. It is used to prepare surfaces for bonding or restorative procedures. It employs an air abrasion system with silica-modified aluminum oxide particles to clean and roughen surfaces. This method is particularly effective for ceramics, as it removes contaminants and creates micro-porosities that enhance adhesive penetration, resulting in stronger bonds. Developed to address the challenges of bonding modern dental materials, especially ceramics like etchable ceramics and hybrid resins, CoJet optimizes micro-porosity creation while minimizing structural damage. The technique allows for better adhesive penetration, leading to more durable bonds, and is versatile enough to be used on various dental materials for different restorations. Its precision in controlling surface roughness ensures optimal conditions for effective bonding, making it a significant advancement in dental surface preparation techniques (Levartovsky et al., 2023).

In conclusion, the surface treatment using Cojet Sand combined with silane and adhesive significantly enhances the bond strength between metal surfaces and resin cement compared to treatments using 50-um and 120-um Al_2O_3 particles. However, the bond strength achieved with Cojet Sand is not significantly different from that obtained with 250-um Al_2O_3 particles. The larger size of the 250-um Al_2O_3 particles compensates for the lack of silane modification, indicating that both mechanical interlocking and chemical adhesion are crucial factors in achieving strong bonds (Garcia et al., 2012).

4.3.2. Conditioning with hydrofluoric acid

Utilizing hydrofluoric acid on leucite reinforced ceramics is an essential element in achieving a robust and long-lasting dental restoration (Figure 44). This chemical process encourages the development of hexafluorsilicate, which is subsequently eliminated by a powerful water jet. The result is a honeycomb-like surface that provides ideal micromechanical retention for cement, delivering a trustworthy and durable restoration (Amorim et al., 2018).

Solutions of hydrofluoric acid (HF) applied for a duration of 2 to 3 minutes with concentration ranges from 2.5% to 10% have shown to be the most effective (Alex, 1995). The quantity, dimensions, and arrangement of leucite crystals can influence the development of micro-porosities that are formed during acid etching. Leucite crystals grow during the ceramic-firing cooling phase. Certain glass ceramics and low-fusing ceramics have minimal amounts of leucite crystals, which might prevent HF acid etching from creating highly-retentive microporosities. For IPS Empress, a leucite-reinforced feldspathic porcelain, the application of a 9% hydrofluoric acid (HF) solution for a duration of 60 seconds. provide the best results (Blatz et al., 2003).

It has been observed that conditioning has no effect on systems containing high alumina content, like the aluminized and zirconium-based ceramic system (Shenoy et al., 2022). This could be because of the low glassy phase and silica content. However, in certain cases, when the resin cement is applied, there may be a reduction in bond strength (Amorim et al., 2018).

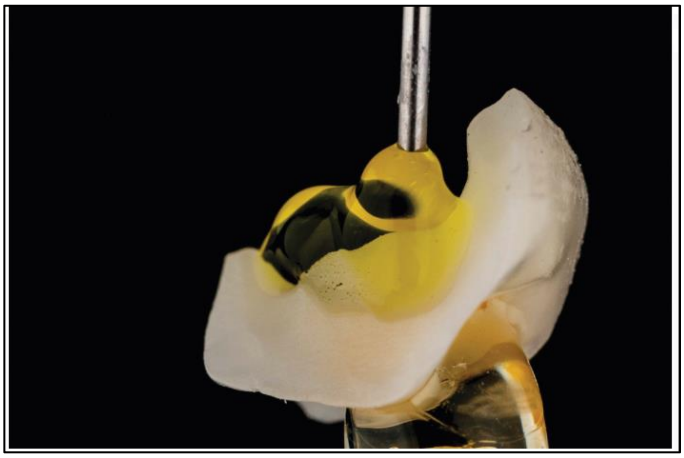


Figure 44: Acid etching with 9.8% HF acid for 1 minute (Adapted from Markus B. Blatz & Amirah Alammar, 2023).

4.3.3. Silanization

Pre-treating the ceramic's internal surface with silane coupling agent creates a chemical covalent and hydrogen bond, which is a significant factor for achieving a resin bond to silica-based ceramics (Figure 45) (Alex, 1995).

Silanes are molecules that possess two functional groups which facilitate the bonding of silicone dioxide to the hydroxyl (OH) groups present on the ceramic surface. In addition, they possess a degradable functional group that conducts copolymerization with the organic matrix of the resin (Amorim et al., 2018).

The process of silanization increases the ceramic surface's wettability. A study conducted by Sorensen et al found that Microleakage was significantly lowered by ceramic etching and silanization, which is not possible with only silane treatment (Sorensen et al., 1991).

However, the efficacy of silanes after try-in procedures or resilanation of the ceramic restoration shows varying results. Bond strengths may decrease due to residual organic contaminants, which should be eliminated before bonding using phosphoric acids or solvents like acetone or alcohol. Unhydrolyzed single-liquid silane primer, pre-hydrolyzed single-liquid silane primer, and 2- or 3-liquid silane primer are the three primary categories of silane primers. Solvent concentrations in silane coupling agents are usually high. Single-bottle products have a short lifespan and are subject to quick solvent evaporation and hydrolysis, making the silane solution unused (Powers et al., 2018).

Several ceramic-bonding systems need a distinct silane preparation prior to the application of a bonding agent and the composite cement (Blatz et al., 2003; Temp et al., 2024).

Figure 45: Application of silane coupling agent (Adapted from Markus B. Blatz & Amirah Alammar, 2023).

In summary, the characteristic fatigue strength of both feldspathic glass-ceramic and lithium disilicate glass-ceramic remains unaffected by surface treatments with hydrofluoric acid (HF) + silane (SIL) or etch and prime. However, only feldspathic glass-ceramic treated with HF + SIL shows an increase in roughness and surface area. Nonetheless, topographic changes are also noticeable in lithium disilicate through microscopy images. These observations suggest that while surface treatments may not impact fatigue strength, they do have differing effects on surface morphology across different types of glass-ceramics (Mokhtar et al., 2024; Shenoy et al., 2022; Temp et al., 2024).

4.4. Bonding

Resin cements can be divided into adhesive or self-adhesive cements. When using adhesive cements, the tooth should be pre-etched with phosphoric acid, followed by the application of an adhesive system, which provides the best long-term adhesive results. These cements are often based on dimethacrylate composites, such as Variolink II® and NX3®. Included among these adhesives are also composite resins for restoration, which have a photonic-only cure and higher viscosity, sometimes requiring pre-heating to 60°C to facilitate handling, as with G-aenial® and Estelite Sigma Quick® (Heboyan et al., 2023). Pre-heating reduces viscosity, providing better marginal adaptability, and increases microhardness, stiffness, and the degree of conversion. Different types of resins and their various compositions react differently to this technique. It raises the pulp temperature, which can be harmless to the pulp tissue when the preheated resin reaches up to 60°C. This technique is simple, safe, fast, and suitable for clinical implementation, though color stability and polymerization shrinkage are still controversial and warrant further research (Lazo et al., 2023).

For self-adhesive cements, acid treatment and adhesive application are not required, except for enamel preparation, where acid etching is still beneficial for increased bond strength values. Self-adhesive or self-etching resin cements include components in their composition that promote bond strength to both the substrate and the restoration simultaneously, such as the MDP (10-Methacryloyloxydecyl dihydrogen phosphate) molecule (Heboyan et al., 2023).

All posterior porcelain restorations currently available benefit from the use of resin cement, except for zirconia, which is an exception. However, resin cements are still recommended for low macro-mechanical retention preparations of zirconia. Resin cements are also classified based on the polymerization process: chemical-cure, light-cure, or dual-cure (Sinha, 2023). Light-cured resins offer long-term color stability, making them advantageous, while dual-cured cements tend to slightly move to a yellow shade over time. It is recommended to use light-cured resin cements for exemple Variolink II (Ivoclar Vivadent), NX3 (Kerr), CHOICE 2 (BISCO) or Rely X Veneer (3M ESPE), for most anterior units to avoid shade shifting issues. For restorations that are thicker or have a high opacity, dual-cure resin cements such as NX3, Variolink Dual Cure (Ivoclar Vivadent), or DUO-LINK (BISCO) are utilized to ensure maximum polymerization, especially with zirconia crowns and partial restorations like inlays and onlays. These thicker posterior restorations' slight color shift are almost imperceptible (Powers et al., 2018).

During placement, the resin cement is applied to both the restoration and the preparation. The restoration is carefully positioned in the mouth with the carrier to ensure proper alignment with the preparation. Once inserted, it is held in place with an appropriately-sized ball burnisher while the carrier is removed. A brush is used to remove extra cement, leaving a small amount at the margins. The restoration is then seated using consistent force with the ball burnisher, ensuring no gaps in the cement at the margins. It is essential not to lift the force prematurely until the initial cure begins to prevent the formation of gaps (Markus B. Blatz & Amirah Alammar, 2023).

The resin cement needs to be light-cured for 20 seconds to achieve a gel-like state in the cement. During this phase, it is important to secure the restoration in position with the ball burnisher while cleaning the interproximal areas and removing any remaining cement from the embrasures using a No. 12 scalpel (Politano et al., 2018).

Next, apply a thin layer of glycerin to the restoration's margins while completing the cure. This will prevent the occurrence of an inadequately cured oxygen-inhibited layer in the cement (Politano et al., 2018).

The following figure (Figure 46) shows the different steps for bonding ceramic restoration in posterior tooth.

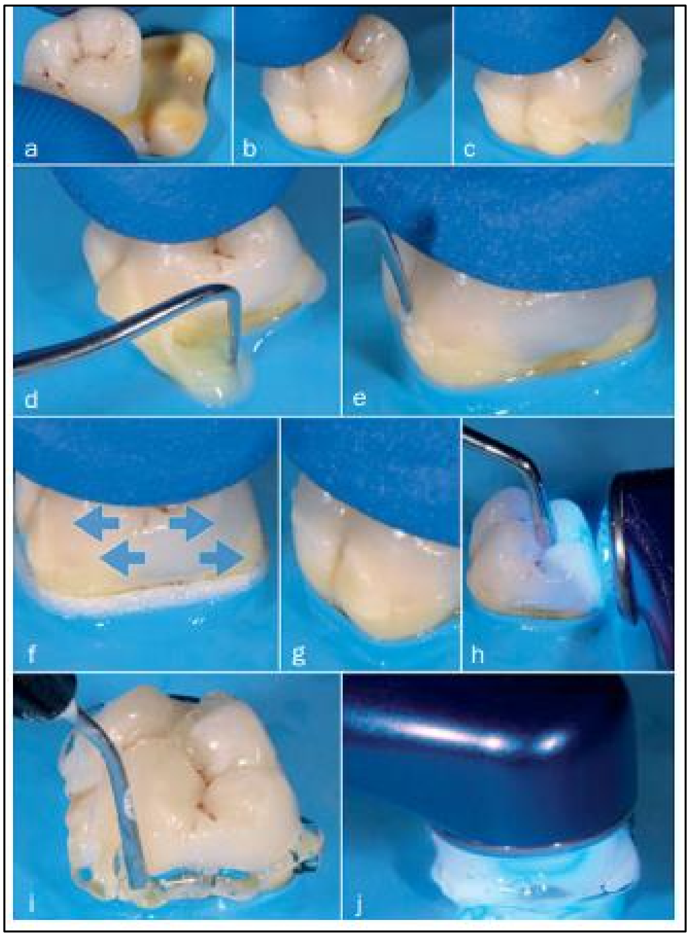


Figure 46: Bonding ceramic restoration (Adapted from Politano et al., 2018).

4.5. Finishing and polishing

To finalize the porcelain restorations, it is recommended to recontour the marginal areas for a smooth transition from tooth to porcelain. This step will increase the longevity of the restoration. Use a fine diamond bur for any adjustments to the porcelain (Figure 47).

After the rubber dam is removed, it's important to check and adjust the occlusion precisely. For dry surfaces, utilize a C-fold towel. Opt for an 80-µm Red towel while performing excursive movements and select a 20-µm Blue towel to enhance visibility and highlight the intricate features of the contacts. Utilize a fine diamond bur to make necessary adjustments, followed by polishing with the Diamond Ceramic Polisher Kit (Politano et al., 2018).

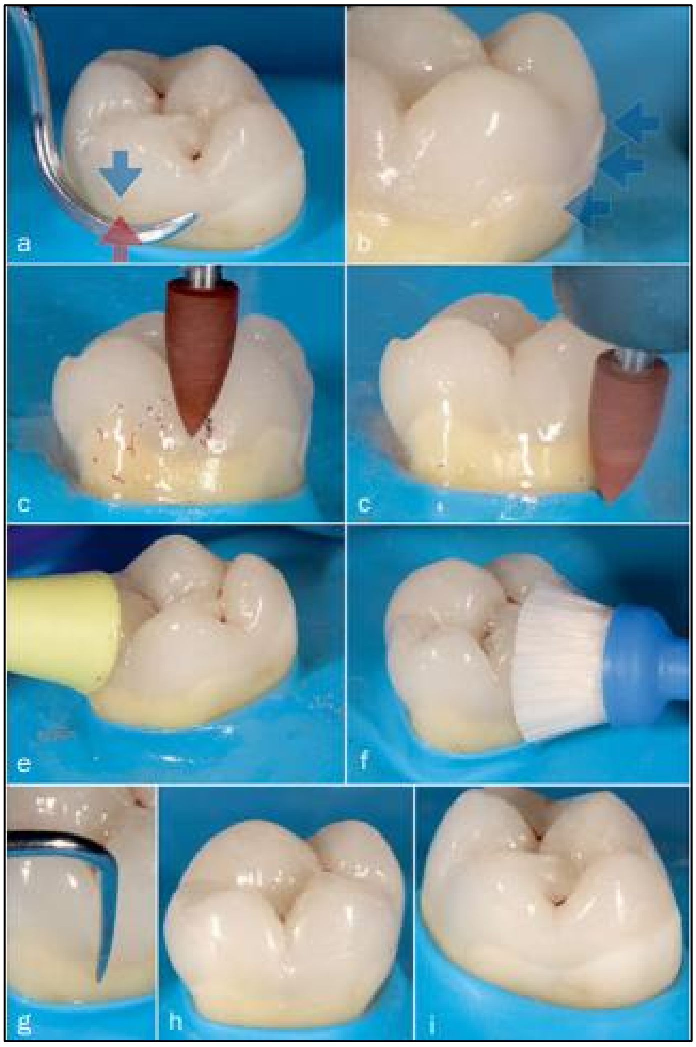


Figure 47: Finishing and occlusion control after bonding (Adapted from Politano et al., 2018).

4.6. Summary of bonding clinical steps

1- After leaving the laboratory, restorations are frequently tried in on both the working cast and in the mouth (Markus B. Blatz & Amirah Alammar, 2023).

2- Isolation with rubber-dam: Rubber dam isolation must be used in adhesive dentistry, enamel and dentin bond strenghs are significantly higher with rubber dam independent of bonding agent (Falacho et al., 2023).

3- Clean preparation with air abrasion or brush.

4- Apply phosphoric acid 35% for 30s enamel and 15 s dentin : bonded ceramic restoration with more than 50% of exposed dentin , IDS significantly increased survival rate 96.4% (Josic et al., 2022).

5- Rinse and dry

6- Apply bonding adhesive.

7- Etching with HF acid:

- Felspathic ceramic 9.8% for 1-2 minutes
- Leucite reinforced glass ceramic 9.8% for 1 minute
- Lithium silicate ceramics 4.6 % for 20 seconds
- Polymer infiltrated ceramic 9.8% for 1 minute.

8- Rinse and dry.

9- Clean in ultrasonic bath and alcohol for 5 min.

10- Apply silane for 20 seconds and dry.

11-Apply bonding adhesive.

12- Apply resin cement and insert restoration.

13- Photopolymerization.

14- Finish restoration and occlusion control.

III. CONCLUSION

Advances in restorative dentistry have become increasingly significant in meeting patient expectations, especially concerning posterior restorations. Indirect ceramic restorations present a conservative alternative for managing large cavities and effectively overcome several limitations associated with direct composite restorations.

Minimally invasive restorations are based on two fundamental principles: tissue preservation, with the objective of conserving as much natural dental tissue as possible, and adhesion, which ensures a strong and durable bond between resin and ceramic.

The longevity of ceramic restorations is intimately dependent on the quality of the bonding interaction. There are many factors that can influence the predictability of the bond achieved when adhesively cementing indirect restorations.

The longevity and success of indirect restorations rely on the collaborative efforts of both patients and operators. Patient factors such as oral hygiene, diet, and habits impact restoration durability, while operator skills in tooth preparation, impression-taking, ceramic material properties, and bonding techniques are equally vital.

The advancement of ceramic and hybrid materials provides exceptional aesthetic and mechanical alternatives that may now satisfy the ever-growing requirements of restorations that are becoming more conservative.

With the advent of new materials and techniques, practitioners now have the opportunity to propose ultra-thin restorations, thanks to completely additive approaches. This approach, often combined with the no prep or prep less concept, reduces the amount of dental tissue removed to a minimum, thereby preserving the natural dental structure to a maximum.

In order to ensure the success of these ultra-thin restorations, it is essential to choose a bonding protocol suitable for the ceramic material used. Advances in the performance of ceramics, bonds and shaping techniques now enable exceptional aesthetic and functional results, while preserving the health of the surrounding dental tissue

IV. Bibliography

A. McLaren, E., Figueira, J., & E. Goldstein, R. (2015). Vonlays: A Conservative Esthetic Alternative to Full-Coverage Crowns. *Compendium of Continuing Education in Dentistry*, *36*(4), 282–289.

Abad-Coronel, C., Naranjo, B., & Valdiviezo, P. (2019). Adhesive systems used in indirect restorations cementation: Review of the literature. In *Dentistry Journal* (Vol. 7, Issue 3). MDPI Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/dj7030071

Abu-Naba'a, L. A. (2023). A Narrative Review of Recent Finite Element Studies Reporting References for Elastic Properties of Zirconia Dental Ceramics. In *Ceramics* (Vol. 6, Issue 2, pp. 898–911). MDPI. https://doi.org/10.3390/ceramics6020052

Adrien, L., & Emmanuel, I. (2020). *Evolution des formes de préparation pour inlays, onlays et overlays postérieurs à la mandibule*. https://www.researchgate.net/publication/347079082

Alex, G. (1995). *Preparing porcelain surfaces for optimal bonding*. https://www.researchgate.net/publication/23261820

Alghazali, N., Moaleem, M., Alamri, S., Aldosari, A. A., Preston, A., Smith, P., & Jarad, F. (2018). The Effect of Try-In Paste and Resin Cement Shade on Colour Properties of Dental Veneers. *The European Journal of Prosthodontics and Restorative Dentistry*, *26*(3), 144–151. https://doi.org/10.1922/EJPRD_01768Alghazali08

Alves de Lucena M et al. (2021). Resin matrix ceramics – mechanical, aesthetic and biological properties. *RGO - Revista Gaúcha de Odontologia*, *69*. https://doi.org/10.1590/1981-86372021001820190130

Amorim, R., Vermudt, A., Pereira, J. R., & Pamato, S. (2018). The surface treatment of dental ceramics: an overview. *Journal of Research in Dentistry*, *6*(4), 80. https://doi.org/10.19177/jrd.v6e4201880-85

Atlan, A. (2015). Les materiaux céramiques, que faut-il en retenir ?Anthoney.

L'Information Dentaire N°29.

Bajraktarova-Valjakova, E., Korunoska-Stevkovska, V., Kapusevska, B., Gigovski, N., Bajraktarova-Misevska, C., & Grozdanov, A. (2018). Contemporary dental ceramic materials, a review: Chemical composition, physical and mechanical properties, indications for use. In *Open Access Macedonian Journal of Medical Sciences* (Vol. 6, Issue 9, pp. 1742–1755). Open Access Macedonian Journal of Medical Sciences. https://doi.org/10.3889/oamjms.2018.378

Barabanti, N., Preti, A., Vano, M., Derchi, G., & Mangani, F. (2015). Indirect composite restorations luted with two different procedures: a ten years follow up clinical trial. *Journal of Clinical and Experimental Dentistry*, *7*(1), 54–59.

Barrantes, J. C. R. (2020). Functional Rehabilitation with an Onlay Ceramic Adhesive Restoration: Case Report. *Odovtos - International Journal of Dental Sciences*, *22*(2), 19–45. https://doi.org/10.15517/IJDS.2020.39214

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. In *Dental Clinics of North America* (Vol. 61, Issue 4, pp. 713–731). W.B. Saunders. https://doi.org/10.1016/j.cden.2017.06.001

Beier, U. S., Kapferer, I., Burtscher, D., M., J., Giesinger, & Dumfahrt, H. (2012). *Clinical Performance of All-Ceramic Inlay and Onlay Restorations in Posterior Teeth*.

Bindl, A., Richter, B., & Mörmann, W. (2005). Survival of ceramic computer- aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. *Int J Prosthodont*, *18(3)*, 219– 24.

Blatz, M. B., Chiche, G., Bahat, O., Roblee, R., Coachman, C., & Heymann, H. O. (2019). Evolution of Aesthetic Dentistry. *Journal of Dental Research*, *98*(12), 1294–1304. https://doi.org/10.1177/0022034519875450

Blatz, M. B., Dent, M., Sadan, A., & Kern, M. (2003). Resin-ceramic bonding: a review of the literature silica-based ceramics. In *Journal Of Prosthetic Dentistry* (Vol. 27, Issue 23).

Bonnafous, D. (2018). *Les restaurations partielles collées dans le traitement de molaires dépulpées*.

Buduru, S., Almasan, O., Todea, M., Mitariu, L., Mitariu, M., Pacurar, M., & Taut, M. (2022). Conventional compared to CAD/CAM ceramic inlay. *Romanian Journal of Stomatology*, *68*(2), 82–89. https://doi.org/10.37897/RJS.2022.2.6

Bustamante-Hernández, N., Montiel-Company, J. M., Bellot-Arcís, C., Mañes-Ferrer, J. F., Solá-Ruíz, M. F., Agustín-Panadero, R., & Fernández-Estevan, L. (2020). Clinical behavior of ceramic, hybrid and composite onlays. A systematic review and meta-analysis. In *International Journal of Environmental Research and Public Health* (Vol. 17, Issue 20, pp. 1–23). MDPI AG. https://doi.org/10.3390/ijerph17207582

Caracaş, A. M., Manolea, H. O., Mitruţ, I., Caracaş, R. E., Ţârtea, D. A., Drăghici, M. A., & Nistor, C. M. L. (2021). The Frequency of Dental Materials Use for Fixed Prostheses in a General Dental Practice. *Curr Health Sci J.*, *47(3):*, 393–397. https://doi.org/10.12865/CHSJ.47.03.09

Çelik, E., & Göktepe, B. (2019). Optical properties of novel resin matrix ceramic systems at different thicknesses. *Cumhuriyet Dental Journal*, *22*(2), 176–184. https://doi.org/10.7126/cumudj.512729

Clausen, N., & Steeb, J. (1976). Toughening of Ceramic Composites by Oriented Nucleation of Microcracks. *Journal of the American Ceramic Society*.

Collares, K., Corrêa, M., Laske, M., Kramer, E., Reiss, B., Moraes, R., Huysmans, M., & Opdam, N. (2016). A practice-based research network on the survival of ceramic inlay/onlay restorations. *Dental Materials*, *32(5)*, 687–694.

D'Incau, E., & Bartala, M. (2011). *Traitement de la dent dépulpée postérieure. La stratégie de la préservation*. https://www.researchgate.net/publication/277141603

D'Incau, E., & Zunzarren, R. (2014). *Evolution des formes de préparation pour inlays/onlays postérieurs à la mandibule*. https://www.researchgate.net/publication/277141743

Deniz, S. T., & Oglakci, B. (2021). *The effect of immediate dentin sealing with chlorhexidine pretreatment on the shear bond strength of dual-cure adhesive cement*. *April*, 3204–3210. https://doi.org/10.1002/jemt.23878

Denry, I., & Holloway, J. A. (2010). Ceramics for dental applications: A review. *Materials*, *3*(1), 351–368. https://doi.org/10.3390/ma3010351

Denry, I. L. (1996). *Recent advances in ceramics for dentistry*.

Derchi, G., Marchio, V., Borgia, V., Özcan, M., Giuca, M., & Barone, A. (2019). Twelve-year longitudinal clinical evaluation of bonded indirect composite resin inlays 50(6). *Quintessence International*, 448–454.

Deubener, J., Allix, M., Davis, M. J., Duran, A., Höche, T., Honma, T., Komatsu, T., Krüger, S., Mitra, I., Müller, R., Nakane, S., Pascual, M. J., Schmelzer, J. W. P., Zanotto, E. D., & Zhou, S. (2018). Updated definition of glass-ceramics. *Journal of Non-Crystalline Solids*, *501*, 3–10. https://doi.org/10.1016/j.jnoncrysol.2018.01.033

Dietschi, D., Duc, O., Krejci, I., & Sadan, A. (2008). Biomechanical considerations for the restoration of endodontically treated teeth: A systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). In *Quintessence Int* (Vol. 39).

Dietschi D, D. O. A. S. (2007). *Biomechanical considerations for the restoration ofendodontically treated teeth: A systematic review ofthe literature—Part 1. Composition and micro- andmacrostructure alterations*.

Edelhoff, D., Güth, J. F., Erdelt, K., Brix, O., & Liebermann, A. (2019). Clinical performance of occlusal onlays made of lithium disilicate ceramic in patients with severe tooth wear up to 11 years. *Dental Materials*, *35*(9), 1319–1330. https://doi.org/10.1016/j.dental.2019.06.001

Edelhoff, D., & Sorensen, J. (2002). *Tooth Structure Removal Associated with Various Preparation Designs for Posterior Teeth*. https://www.researchgate.net/publication/11201892

Elagra, M. E. (2019). Endocrown preparation: Review. *~ 253 ~ International Journal of*

Applied Dental Sciences, *5*(1), 253–256. www.oraljournal.com

Étienne, O., & Watzki, D. (2017). *Reconstruction of occlusal surfaces with bonded ceramic overlays*.

Fages, M. (2013). The Endocrown: A Different Type of All-Ceramic Reconstruction for Molars Evaluating intra-oral cameras View project. In *Article in Journal (Canadian Dental Association*. https://www.researchgate.net/publication/259205029

Falacho, R. I., Melo, E. A., Marques, J. A., Ramos, J. C., Guerra, F., & Blatz, M. B. (2023). Clinical in-situ evaluation of the effect of rubber dam isolation on bond strength to enamel. *Journal of Esthetic and Restorative Dentistry*, *35*(1), 48–55. https://doi.org/10.1111/jerd.12979

Fan, J., Xu, Y., Si, L., Li, X., Fu, B., & Hannig, M. (2021). Long-term Clinical Performance of Composite Resin or Ceramic Inlays, Onlays, and Overlays: A Systematic Review and Meta-analysis. *Operative Dentistry*, *46*(1), 25–44. https://doi.org/10.2341/19-107-LIT

Fernando C, P. F. F. V. (2011). Dental Materials Influence of chlorhexidine application on longitudinal adhesive bond strength in deciduous teeth. In *Dental Materials* (Vol. 388, Issue 5).

Ferraris, F. (2017). Posterior indirect adhesive restorations (PIAR): preparation designs and adhesthetics clinical protocol. In *The International Journal Of Esthetic Dentistry Winter*.

Fonzar RF, & Cecilia Goracci, M. C. C. L. M. F. A. V. (2020). Influence of Acid Concentration and Etching Time on Composite Cement Adhesion to Lithium-silicate Glass Ceramics. *J Adhes Dent*, 175–182.

Garcia, R., Gagliardi, I., & Alves, A. (2012). *Efficacy of Air-abrasion Technique and Additional Surface Treatment at Titanium / Resin Cement Interface*. *14*(5), 453–459. https://doi.org/10.3290/j.jad.a23444

Gealh, C., Escobar, N., Dominguez, J. A., & Gomes, G. M. (2023). *Effectiveness of two adhesive universal with functional monomers on enamel and dentin with different* *application modes*. *8*(2), 31–49.

Gierthmuehlen, P. C., Spitznagel, F. A., Koschate, M., Bonfante, E. A., & Prott, L. S. (2023). Influence of ceramic thickness and dental substrate on the survival rate and failure load of non-retentive occlusal veneers after fatigue. *Journal of Esthetic and Restorative Dentistry*. https://doi.org/10.1111/jerd.13103

Gracis, S., Thompson, V., Ferencz, J., Silva, N., & Bonfante, E. (2016). A New Classification System for All-Ceramic and Ceramic-like Restorative Materials. *The International Journal of Prosthodontics*, *28*(3), 227–235. https://doi.org/10.11607/ijp.4244

Guastalla, O., Viennot, S., & Allard, Y. (2005). Bonding in odontology. In *EMC-Odontologie* (Vol. 1, Issue 3, pp. 193–201). Elsevier Masson SAS. https://doi.org/10.1016/j.emcodo.2005.07.001

Hajtó.J, M. C. A. . (2013). Inlays et onlays en céramique :critères de succès. *Réalités Cliniques* , *Vol. 24*(n°4), 99–104.

Hassan, A., Hamdi, K., Ali, A. I., Al, W., Salah, Z., & Mahmoud, H. (2023). Clinical performance comparison between lithium disilicate and hybrid resin nano - ceramic CAD / CAM onlay restorations : a two - year randomized clinical split - mouth study. *Odontology*, *0123456789*. https://doi.org/10.1007/s10266-023-00841-w

Heboyan, A., Vardanyan, A., Karobari, M. I., Marya, A., Avagyan, T., Tebyaniyan, H., Mustafa, M., Rokaya, D., & Avetisyan, A. (2023). Dental Luting Cements: An Updated Comprehensive Review. *Molecules*, *28*(4), 1–16. https://doi.org/10.3390/molecules28041619

Helvey, G. (2013). *Classification of Dental Ceramics*. www.dentalaegis.com/id

Hu, S. N., Li, J. W., Zhang, X. X., Wei, R., & Liang, Y. H. (2024). Outcome of chairside CAD/CAM ceramic restorations on endodontically treated posterior teeth: a prospective study. *BMC Oral Health*, *24*(1). https://doi.org/10.1186/s12903-023-03812-3

ivoclar vivadent. (2013). How to properly clean restorations after try-in. *Information*

Provided by Ivoclar Vivadent Inc.

Jalali, S., Jalali, H., Kharazi Fard, M. J., Abdolrahmani, A., & Alikhasi, M. (2023). The effect of preparation design on the fracture resistance and adaptation of the CEREC ceramic endocrowns. *Clinical and Experimental Dental Research*, *9*(3), 518–525. https://doi.org/10.1002/cre2.726

Jenkins, M. G., & Salem, J. A. (2018). International standards for properties and performance of advanced ceramics-three decades of high-quality, technically-rigorous normalization. *Ceramic Transactions*, *261*, 59–80. https://doi.org/10.1002/9781119423829.ch6

Josic, U., Sebold, M., Lins, R. B. E., Savovic, J., Mazzitelli, C., Maravic, T., Mazzoni, A., & Breschi, L. (2022). Does immediate dentin sealing influence postoperative sensitivity in teeth restored with indirect restorations? A systematic review and meta-analysis. In *Journal of Esthetic and Restorative Dentistry* (Vol. 34, Issue 1, pp. 55–64). John Wiley and Sons Inc. https://doi.org/10.1111/jerd.12841

Jurado, C. A., Fischer, N. G., Sayed, M. E., Villalobos-Tinoco, J., & Tsujimoto, A. (2021). Rubber Dam Isolation for Bonding Ceramic Veneers: A Five-Year Post-Insertion Clinical Report. *Cureus*. https://doi.org/10.7759/cureus.20748

Katta, P. K., Rajalbandi, S., & Sreedhara, S. (2016). Enamel and Dentin Adhesion Mechanism. *Indian Journal of Contemporary Dentistry*, *4*(1), 7. https://doi.org/10.5958/2320-5962.2016.00002.4

Kolakarnprasert, N., Kaizer, M. R., Kim, D. K., & Zhang, Y. (2019). New multi-layered zirconias: Composition, microstructure and translucency. *Dental Materials*, *35*(5), 797–806. https://doi.org/10.1016/j.dental.2019.02.017

Kongkiatkamon, S., Rokaya, D., Kengtanyakich, S., & Peampring, C. (2023). Current classification of zirconia in dentistry: an updated review. In *PeerJ* (Vol. 11). PeerJ Inc. https://doi.org/10.7717/peerj.15669

Lazo, G. E. O., Serrano, P. P. A., & Tamariz, O. P. E. (2023). Preheated resin as a cementing agent in fixed prosthesis: Literature review. *World Journal of Advanced Research and Reviews*, *18*(1), 573–584.

https://doi.org/10.30574/wjarr.2023.18.1.0632

Levartovsky, S., Ferdman, B., Safadi, N., Hanna, T., Dolev, E., & Pilo, R. (2023). *Effect of Silica-Modified Aluminum Oxide Abrasion on Adhesion to Dentin , Using Total-Etch and Self-Etch Systems*.

Magdy, H., Mahallawi, O. S. El, & Nabil, O. (2023). Efficacy of preparation design on fracture resistance of hybrid-ceramic endo-crown on premolars: An in vitro study. *International Journal of Applied Dental Sciences*, *9*(1), 12–18. https://doi.org/10.22271/oral.2023.v9.i1a.1649

Mandal, N., Kumari, A., Baldev, K., Sarangi, P., Chauhan, R., Rajesh, D., & Tiwari, H. (2022). A clinical evaluation of onlay and inlay in the posterior ceramic restorations: An original study. *Journal of Pharmacy And Bioallied Sciences*, *14*(5), 310. https://doi.org/10.4103/jpbs.jpbs_776_21

Manuja, N., Nagpal, R., & Pandit, I. K. (2012). Dental adhesion. In *Journal of Clinical Pediatric Dentistry* (Vol. 36, Issue 3, pp. 223–234). Journal of Clinical Pediatric Dentistry. https://doi.org/10.17796/jcpd.36.3.68805rl1r037m063

Markus B. Blatz, & Amirah Alammar, J. M. A. (2023). *How to Bond to Current CAD/CAM Ceramics*.

Mokhtar, A., Hussein, G., & Wahsh, M. (2024). Effect of Different Surface Treatments on Bond Strength of Resin Cement with Lithium Silicate Ceramics. *Al-Azhar Journal of Dental Science*, *27*(1), 47–57. https://doi.org/10.21608/ajdsm.2022.168334.1373

Montazerian, M., Baino, F., Fiume, E., Migneco, C., Alaghmandfard, A., Sedighi, O., Deceanne, A. V, Wilkinson, C. J., & Mauro, J. C. (2023). Glass-ceramics in dentistry : Fundamentals , technologies , experimental techniques , applications , and open issues. *Progress in Materials Science*, *132*(August 2022), 101023. https://doi.org/10.1016/j.pmatsci.2022.101023

Otto, T. (2017). Up to 27-years clinical long-term results of chairside Cerec 1 CAD/CAM inlays and onlays. *Int J Comput Dent*, *20*(3), 315-329.

Özcan, M., Dündar, M., & Erhan Çömlekoğlu, M. (2012). Adhesion concepts in dentistry: Tooth and material aspects. In *Journal of Adhesion Science and Technology* (Vol. 26, Issue 24, pp. 2661–2681). Taylor and Francis Ltd. https://doi.org/10.1080/01694243.2012.691038

Pallesen, U., & Qvist, V. (2003). Composite resin fillings and inlays. An 11-year evaluation. *Clin Oral Investig*, *7*, 71–79.

Pawar, S., Lekhwani, V., Ahmed, H., Agrawal, P., Barapatre, P., Sharma, P., Gupta, S., & Gupta, B. (2022). Ceramic Inlays: A Case Report. *Cureus*. https://doi.org/10.7759/cureus.29043

Perdigão, J., Araujo, E., Ramos, R. Q., Gomes, G., & Pizzolotto, L. (2021). Adhesive dentistry: Current concepts and clinical considerations. In *Journal of Esthetic and Restorative Dentistry* (Vol. 33, Issue 1, pp. 51–68). Blackwell Publishing Ltd. https://doi.org/10.1111/jerd.12692

Perdigão, J., Walter, R., Miguez, P. A., & Swift, E. J. (2019). Fundamental Concepts of Enamel and Dentin Adhesion. *In Sturdevant's Art and Science of Operative Dentistry*, pp: (136–169).

Pilecco, R. O., Machry, R. V., Ribeiro, V. F., Dal Piva, A. M. de O., Tribst, J. P. M., Kleverlaan, C. J., Moraes, R. R., & Pereira, G. K. R. (2024). Impact of try-in paste removal on the fatigue behavior of bonded lithium disilicate ceramics. *Journal of the Mechanical Behavior of Biomedical Materials*, *151*. https://doi.org/10.1016/j.jmbbm.2024.106394

Politano, G., Van Meerbeek, B., & Peumans, M. (2018). Nonretentive Bonded Ceramic Partial Crowns: Concept and Simplified Protocol for Long-lasting Dental Restorations. *The Journal of Adhesive Dentistry*, *20*(6), 495–510. https://doi.org/10.3290/j.jad.a41630

Powers, J. M., Farah, J. W., O'keefe, K. L., Kolb, B., & Udrys, G. (2018). *Guide to all-ceramic bonding*. Dental Consultants, Inc.

Rekow, E. D., Silva, N. R. F. A., Coelho, P. G., Zhang, Y., Guess, P., & Thompson, V. P. (2011). Performance of dental ceramics: Challenges for improvements. In *Journal* *of Dental Research* (Vol. 90, Issue 8, pp. 937–952). https://doi.org/10.1177/0022034510391795

Rocca, G. T. (2006). *Bonded indirect restorations for posterior teeth: The luting appointment*. https://www.researchgate.net/publication/6145770

Saint Jean S. (2014). *Dental Glasses and Glass-ceramics.* (Heinemann Elsevier). Advanced Ceramics for Dentistry.

Sato, T., Takagaki, T., Hatayama, T., Nikaido, T., & Tagami, J. (2021). Update on Enamel Bonding Strategies. In *Frontiers in Dental Medicine* (Vol. 2). Frontiers Media S.A. https://doi.org/10.3389/fdmed.2021.666379

Shenoy, A., Sivaswamy, V., & Maiti, S. (2022). Bonding Protocol for all Ceramic Restorations-A Proposal for a Clinical Decision Tree. In *Journal of Research in Medical and Dental Science* | (Vol. 10, Issue 2). www.jrmds.in

Shetty, R., Shenoy, K., Dandekeri, S., Syedsuhaim, K., Ragher, M., & and Francis, J. (2015). *Resin-matrix ceramics – an overview*. *6*(11), 7414–7417.

Shi, H. Y., Pang, R., Yang, J., Fan, D., Cai, H. X., Jiang, H. B., Han, J., Lee, E. S., & Sun, Y. (2022). Overview of Several Typical Ceramic Materials for Restorative Dentistry. In *BioMed research international* (Vol. 2022, p. 8451445). NLM (Medline). https://doi.org/10.1155/2022/8451445

Sinha, I. (2023). Adhesive Cementation of Ceramic Restorations: A Comprehensive Review. *INNOSC Theranostics and Pharmacological Sciences*, *6*(1), 28–34. https://doi.org/10.36922/itps.197

Skorulska, A., Piszko, P., Rybak, Z., Szymonowicz, M., & Dobrzyński, M. (2021). Review on polymer, ceramic and composite materials for cad/cam indirect restorations in dentistry—application, mechanical characteristics and comparison. In *Materials* (Vol. 14, Issue 7). MDPI AG. https://doi.org/10.3390/ma14071592

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.

https://doi.org/10.11138/ads/2017.8.1.001

Sorensen, J., Kang, S., & Avera, S. (1991). Porcelain-composite interface mic- roleakage with various porcelain surface treatments. *Dent Mat*, 118–123.

Stawarczyk B, K. C. E. M. F. D. E. D. L. N. (2017). Three generations of zirconia: From veneered to monolithic. Part II. . *Quintessence Int* , *48(6)*, 441–500.

Sultan, S., Al Garni, H., Al Onazi, M., Gangi, K. K., Al Otha, S., Al Ruwaili, F., Al Anazi, S., Al Shammari, M., Fandi, A., & Fayad, M. (2021). Minimally Invasive Posterior Full Crown Competitors: Onlays, Occlusal Veneers, Vonlays and Endocrowns: A Review and Proposed Classification. In *J Int Dent Med Res* (Vol. 14, Issue 4). http://www.jidmr.com

Sutejo, I. A., Kim, J., Zhang, S., Gal, C. W., Choi, Y. J., Park, H., & Yun, H. suk. (2023). Fabrication of color-graded feldspathic dental prosthetics for aesthetic and restorative dentistry. *Dental Materials*, *39*(6), 568–576. https://doi.org/10.1016/j.dental.2023.03.021

Temp, R. W., Packaeser, M. G., Machry, R. V., Dapieve, K. S., Rippe, M. P., Pereira, G. K. R., & Valandro, L. F. (2024). Characteristic fatigue strength and reliability of dental glass-ceramics: Effect of distinct surface treatments – Hydrofluoric acid etching and silane treatment vs one-step self-etching ceramic primer. *Journal of the Mechanical Behavior of Biomedical Materials*, *150*, 106338. https://doi.org/10.1016/j.jmbbm.2023.106338

Tennert, C., Suárez Machado, L., Jaeggi, T., Meyer-Lueckel, H., & Wierichs, R. J. (2022). Posterior ceramic versus metal restorations: A systematic review and meta-analysis. In *Dental Materials* (Vol. 38, Issue 10, pp. 1623–1632). Elsevier Inc. https://doi.org/10.1016/j.dental.2022.08.002

Tirlet, G., & Attal, J. P. (2009). *Gradient thérapeutique un concept médical*.

Traini, T., Sinjari, B., Pascetta, R., Serafini, N., Perfetti, G., Trisi, P., & Caputi, S. (2016). The zirconia-reinforced lithium silicate ceramic: Lights and shadows of a new material. *Dental Materials Journal*, *35*(5), 748–755. https://doi.org/10.4012/dmj.2016-041

Vallerini, B. de F., Silva, L. D., Villas-Bôas, M. de O. C., Peitl, O., Zanotto, E. D., & Pinelli, L. A. P. (2024). Microstructure and mechanical properties of an experimental lithium disilicate dental glass-ceramic. *Ceramics International*, *50*(1), 188–196. https://doi.org/10.1016/j.ceramint.2023.10.093

Van Meerbeek & Others. (2003). Adhesion to Enamel and Dentin: Current Status and Future Challenges. *Operative Dentistry,* , *28*(3), 215–235.

Veneziani, M. (2017). *Posterior indirect adhesive restorations: updated indications and the Morphology Driven Preparation Technique*. https://www.researchgate.net/publication/317022052

Vincent, J., Thakur, S., & Justa, A. (2022). Adhesives in dentistry: present and future; a literature review. *International journal of scientific research*, 60–61. https://doi.org/10.36106/ijsr/5407580

Warreth, A., & Elkareimi, Y. (2020). All-ceramic restorations: A review of the literature. In *Saudi Dental Journal* (Vol. 32, Issue 8, pp. 365–372). Elsevier B.V. https://doi.org/10.1016/j.sdentj.2020.05.004

Wicaksono, S., Prasetia, W., Muryani, A., Dirgantara, T., & Mahyuddin, A. I. (2023). Finite element stress analysis of dental cement application on endocrown and onlay restoration. *Australian Endodontic Journal*, *49*(3), 665–674. https://doi.org/10.1111/aej.12800

Yin, Y., Xu, J., & Chen, M. (2024). A review on surface texturing of zirconia ceramics for dental applications. In *International Journal of Advanced Manufacturing Technology*. Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s00170-024-12948-7

Zhang, Y., & Kelly, J. R. (2017). Dental Ceramics for Restoration and Metal Veneering. In *Dental Clinics of North America* (Vol. 61, Issue 4, pp. 797–819). W.B. Saunders. https://doi.org/10.1016/j.cden.2017.06.005

Zhang, Y., & Lawn, B. R. (2018). Novel Zirconia Materials in Dentistry. *Journal of Dental Research*, *97*(2), 140–147. https://doi.org/10.1177/0022034517737483