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Ceramic restorative materials for fixed prostheses: A literature review

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Abstract
Introduction: The use of restorative materials in dentistry is constantly growing, as they not only improve masticatory and esthetic function, but also directly intervene in the patient's quality of life.
Objective: To analyze restorative ceramic materials for fixed prostheses offering an overview of their resistance to degradation over time, their marginal adjustment and mechanical characteristics without forgetting to consider advantages and limitations according to the type of restoration and the patient's characteristics, such as feldspathic porcelains, leucite reinforced porcelains, silicate ceramics, zirconia and alumina.
Methodology: A systematic search was carried out in databases using the keywords “zirconia”, “yttria-stabilized zirconia” “Full-ceramic”, “lithium disilicate ceramic”, ‘porcelain’, “glass-ceramics”, “feldspathic ceramic”, “alumina”.
Results: Zirconia is identified as the ceramic used in oral rehabilitation with the highest strength support but with poor esthetics compared to other materials. Porcelain, in spite of standing out for its high esthetics, has a low resistance. Silicates represent a middle point, having a very good resistance (not higher than zirconia) and equally high esthetics (not higher than porcelain). Alumina is a dental ceramic that has practically fallen into disuse in the fabrication of fixed prostheses, although it is widely used as an abrasive.
Conclusion: Zirconia excels in strength for load-bearing restorations but lacks esthetics. Porcelain offers superior aesthetics yet requires reinforcement due to lower durability. Lithium disilicate balances strength, translucency, and biocompatibility, ideal for esthetic cases. Alumina is clinically obsolete, limited to abrasive applications. Material selection depends on functional and aesthetic demands.

Keywords: Zirconia, yttria-stabilized zirconia, full-ceramic, lithium disilicate ceramic, porcelain, glass-ceramics, feldspathic ceramic, alumina

1. Introduction
The use of restorative materials in dentistry is constantly growing, as they not only improve masticatory function and esthetics, but also directly intervene in the patient's quality of life [1].
The preference for ceramic restorations is widely recognized due to their superior ability to esthetically replicate tooth morphology, their resistance to degradation over time and their optimized marginal fit [2].
The physical and optical properties of ceramics make them the material of choice for patients with high esthetic and functional expectations, wear resistance and biocompatibility. However, there are advantages and limitations depending on the type of restoration and the characteristics of the patient [3]. Efforts are made to compare materials to ensure that they meet both the mechanical characteristics necessary for the correct functionality of the restoration and the esthetic aspects [4].
The choice of an adequate material for oral rehabilitation is fundamental to ensure the success of the treatment. Understanding the advantages and limitations is essential to prevent possible complications. For this reason, it is necessary to have an efficient method to evaluate the materials, thus guaranteeing optimal and lasting clinical results. The aim of this work was to analyze the literature on dental ceramics, synthesize the available information and provide an overview of the advances and key characteristics of dental ceramics used in restorative

dentistry, such as feldspathic porcelains, leucite-reinforced porcelains, silicate ceramics, zirconia and alumina.

2. Materials and Methods

An electronic search was carried out through PubMed, Google Scholar and Scopus, using the terms: zirconia, porcelains, silicates, alumina, restorative materials, ceramics, using Boolean operators "AND" and "OR". The quality of the articles was evaluated using guidelines tool. As inclusion criteria, only articles from high impact journals were collected, including systematic reviews, literature reviews or clinical studies that treated in behavior management techniques. Likewise, the search was delimited in terms of publication date, taking only recent articles, published mainly within the last 5 years. The selection of articles was made according to the relevance of the title and/or abstract to the topic to be analyzed. After the selection of relevant studies, their references were searched for possible additional relevant studies that met the inclusion criteria.

3. Results & Discussion

3.1. Zirconia

Zirconia, also known as "ceramic steel", is a crystalline dioxide of zirconia [5]. This material in dentistry comes in three phases: monoclinic (at room temperature), tetragonal (above ~1170 °C) and cubic (above ~2370 °C), with the tetragonal being the strongest and most durable, because yttria is added to the zirconia powder to stabilize the tetragonal zirconia at room temperature. The strength of zirconia ceramic is a key factor in its widespread use in dentistry [6]. Still with characteristics of this material, in terms of its nature, it does not contain glass in its composition, so it does not react to conventional hydrofluoric acid etching techniques, which makes it unsuitable for traditional adhesive bonding methods [7].

It is a stable restorative biomaterial, resistant to acid erosive attacks that occur in the mouth (although some erosive agents can have a negative effect on the surface roughness)[8], it has an extremely low thermal conductivity, which avoids the irritability of tissues such as dental pulp; [9] also among the restorative materials used in dentistry, dental zirconia stands out as the material with the highest hardness [10], these characteristics previously mentioned make it a material of first choice as a restorative. Among the different zirconia composites, yttria-stabilized zirconia (which will be discussed later) has the most favorable mechanical properties compared to other high-strength ceramics, with flexural strengths of 700-1200 MPa, fracture toughness of more than 2000 N and fracture toughness of 7-10 MPa [11].

It is characterized for being an aesthetic biomaterial, although its translucency is lower than other ceramics which, by having a higher translucency, have a more aesthetic effect. To maintain the translucency of zirconia prostheses, a suitable cement must be used that contains the necessary characteristics to not cause any affectation to the esthetic finishes [12]. At the same time, once cemented, these crowns have shown less plaque accumulation compared to other materials due to their highly polished surface [13]. The bonding protocol consists of a combination of mechanical-chemical pretreatment, which has been shown to increase bond strength and offer the best clinical results [11]. The mechanical component involves particle abrasion in air using 50 µm Al2O3 particles applied at a pressure of 2.5 bar for 10 seconds, maintaining a distance of 10 mm. As for the chemical treatment, a ceramic primer containing silane and a 10 MDP monomer is used [6]. The classification of resin cements is complex due to the variability in their compositions, which include phosphoric acid esters, 10-MDP, HEMA and dimethacrylates. It is grouped into three categories: self-adhesive, 10-MDP cement and Bis-GMA cement, with internal variability related to component percentages and viscosity. Although the Bis-GMA shows lower adhesion, it is more resistant to hydrolytic degradation. The relationship between 10-MDP adhesives and adhesion is uncertain, and studies offer contradictory results; although cements with MDP already included do not need to be primed. However, the importance of mechanical conditioning of the surface to improve adhesion (sandblasting with aluminum oxide at 50 microns is recognized as the best option) [14]. Once cemented, if it is necessary to adjust it, it is advisable to use a fine-grained diamond rotary instrument, avoiding the use of coarse-grained instruments, and then perform a detailed polishing [15]. Inadequate polishing may result in rough surfaces on the zirconia, which could cause wear on the opposing tooth. However, a highly polished, unglazed zirconia turns out to be more compatible with an opposing natural tooth compared to other ceramics, and even with tooth enamel [16].

The incorporation of yttria (Y_2O_3) in zirconia allows stabilizing its tetragonal phase, reducing grain growth and improving its stability at high temperatures. During thermal degradation, yttria participates in a reaction that induces a phase change in zirconia. Thermal stability of its cubic phase is achieved by partial substitution of Zr^{4+} ions by Y^{3+} ions, of larger ionic radius, resulting in the formation of partially stabilized zirconia (PSZ) [9].

The concentration of yttria in the zirconia composition is a major determinant of the optical and mechanical properties of zirconites. Generally speaking, as the yttria concentration increases, translucency increases, while mechanical strength tends to decrease [6].

In the context of polycrystalline tetragonal zirconia (TZP), various compositions (12 types) have been developed based on the molar content of yttria, with variants such as 3Y-TZP, 4Y-TZP, 5Y-TZP and 6Y-TZP standing out. 3Y-TZP, with 3 molar % yttria, is one of the most widely used formulations in dentistry because of its high mechanical strength, although it has lower translucency. As the yttria content increases, as in 6Y-TZP, translucency improves at the cost of reduced mechanical properties. When the yttria concentration exceeds 8 molar %, a stable cubic phase is obtained at room temperature, known as cubic stabilized zirconia (CSZ). On the other hand, intermediate concentrations of yttria (between 3 and 8 molar %) generate mixtures of cubic and tetragonal phases, resulting in partially stabilized zirconia (PSZ). In particular, 3Y-TZP is characterized by having almost exclusively tetragonal phase, which justifies its designation as polycrystalline tetragonal zirconia [9].

Zirconia - Alumina Composite material presents good fracture resistance, high flexibility and high durability against degradation at low temperatures. Although it is biocompatible, it is recommended for use as an implant accessory due to its low translucency [10].

Pure zirconia (ZrO_2) presents three crystalline phases: monoclinic, tetragonal and cubic, being the monoclinic the stable one at room temperature. The incorporation of stabilizing oxides such as $Y_2O_2O_3$ allows the tetragonal and cubic phases to be maintained at room temperature. With more than 8 molar % yttria stabilized cubic zirconia (CSZ) is obtained, while between 3 and 8 % partially stabilized

zirconia (PSZ) is formed. When the yttria concentration approaches 3 molar %, the tetragonal phase predominates, resulting in polycrystalline tetragonal zirconia (TZP) [10].
Ce-TZP exhibits higher toughness compared to 3Y-TZP, although its flexural strength and hardness are lower, and it has not yet been implemented in practical applications. Attempts were made to improve these properties by incorporating alumina (Al2O3) particles into Ce-TZP, but the results were unsatisfactory. In contrast, 3Y-TZP with 20 volume % alumina shows significant improvements in flexural strength and fracture toughness, being known as alumina toughened zirconia (ATZ). Alternatively, there is alumina in which 20% 3Y-TZP is dispersed by volume, called zirconia hardened alumina (ZTA) [10].

3.2. Porcelains

Dental porcelains are often considered an ideal choice for dental restorations due to their natural appearance, biocompatibility, durability and high translucency [10]. These include conventional feldspathic porcelain, alumina, glass-infiltrated alumina, glass-ceramic, reinforced glass-ceramic (leucite and lithium disilicate) and densely sintered alumina [17]. These have the characteristic of mimicking the properties of natural teeth, making them an attractive option for patients seeking durable dental solutions [18]. They can achieve complete transparency, since it is possible to obtain zero porosity with relative ease. This feature mimics the optical properties of natural teeth, however, they are gradually being supplanted by ceramics that are less vulnerable to fracture, especially chipping [19].
Feldspar glass, widely used in dental ceramics, has a relatively low coefficient of thermal expansion (CTE) (~8 × 10^{-6}/°C). To improve fracture toughness, porcelain is designed with a slightly lower CTE than the underlying metal, which induces beneficial residual compression. The addition of leucite allows the CTE of the porcelain to be adjusted, varying its content from a few percent to 25 wt%, depending on the support material. In addition, leucite acts as a dispersion strengthening agent, as it can be incorporated in high proportions (up to 50 wt%) without significantly affecting translucency, due to its refractive index similar to that of feldspar glass. Commercial examples of leucite-reinforced ceramics include IPS Empress and Finesse All-Ceramic, with flexural strengths of approximately 138 MPa and 125 MPa, respectively [20].
The mechanical performance of glass-ceramics is governed by three fundamental factors: chemical composition, microstructural characteristics, and the nature (tensile/compressive) and degree of residual stresses. Particularly in leucite-based glass-ceramics, thermal residual stress - arising from differential thermal expansion coefficients between crystalline and amorphous phases during cooling - serves as the primary strengthening mechanism [21]. These materials, manufactured through controlled crystallization (ceramming), include notable commercial systems: Dicor (flexural strength σ ≈ 229 MPa; Dentsply), IPS Empress II (σ ≈ 350 MPa; Ivoclar Vivadent), and the more contemporary IPS e.max Press/CAD systems (σ ≈ 480 MPa; Ivoclar Vivadent). Their inherent translucency enables fabrication of monolithic restorations [20]. Alternative formulations incorporating alumina demonstrate improved mechanical properties (σ ≈ 120 MPa) at the expense of optical characteristics [20]. The In-Ceram Alumina system, developed from Sadoun's innovative glass-infiltration technique, creates a bicontinuous alumina-glass network with 70 vol% alumina content, achieving σ ≈ 450 MPa [21]. Subsequent derivatives include In-Ceram Spinel (enhanced translucency/reduced strength) and In-Ceram Zirconia (increased strength/decreased translucency). This inverse relationship between esthetics and fracture resistance significantly constrains the clinical applications of highly aesthetic porcelains [20]. Notably, feldspathic and silicate-based systems exhibit elevated failure incidence in posterior applications, primarily due to insufficient mechanical properties compared to contemporary alternatives like zirconia [22].
Feldspathic porcelains consist primarily of potassium feldspar, with a crystalline content below 20% by weight and an average crystal size of 4 µm [23].
Renowned for their aesthetics, leucite-reinforced feldspathic ceramics demonstrate exceptional long-term performance when bonded to enamel substrates. Clinical studies report survival rates of 92% for inlays/onlays (8 years), 94% for veneers (12 years), and 95% for crowns (11 years) [20]. These materials are particularly suitable for restorations preserving substantial natural tooth structure.
Their highly vitreous composition permits unimpeded light transmission for complete resin cement polymerization [24]. However, their relatively low flexural strength [25]—especially compared to other glass-ceramics [26]—necessitates adhesive cementation.
Final shade is influenced by cement selection and ceramic thickness, with cement choice critically affecting thin restorations' appearance [27]. Surface preparation requires hydrofluoric acid etching (optimally 1% or 10% concentrations) to enhance micromechanical retention, as 5% concentration may compromise fatigue resistance [28, 29].
Leucite is a rock-forming mineral composed of potassium aluminosilicate. At room temperature, leucite has a tetragonal structure. However, the crystalline structure undergoes a tetragonal to cubic phase transformation at 625 °C. This phase transformation is accompanied by a volume expansion of 1.2%, resulting in a high CTE (20 - 25 × 10-6/°C) [30].
Dispersion strengthening is one of the most robust methods for strengthening glass-ceramics. One of the most successful particulate fillers used in dental glass-ceramics is leucite. An example of a commercial dental ceramic containing leucite as a reinforcing phase shows a flexural strength of ~138 MPa [30].
Its strength is almost twice that of traditional feldspathic porcelains, but not sufficient for use as posterior fixed dental prostheses. Regarding flexural strength, the polished samples presented an average value of 82.83 MPa, while the glazed samples presented an average value of 152.87 MPa [31].

3.3. Silicates

Its outstanding esthetics make it a particularly suitable material for monolithic restorations [32]. It exhibits good mechanical properties and optical characteristics, with a flexural strength of 370±50 MPa and a fracture toughness (KIC) of 2.8-3.5 MPa√m) [33]. These properties are suitable for application in the anterior tooth region, however it changes depending on patient conditions [34].
Silicates are noted for good flexural strength and a high ability to prevent fracture, however the most outstanding characteristics are their high degree of translucency and low adhesion to microorganisms. Its mechanical properties are due to a tightly interlocked, layered distribution of elongated disilicate crystals, which makes crack propagation difficult [20].
For the conversion of metasilicate crystals into lithium

disilicate (~70%) it must undergo a heating process at 840°-850 °C, increasing the flexural strength to values of 262 ± 88 MPa, along with a fracture toughness of 2.5MPa-m1/2 [35].

One of the most outstanding aspects is its biocompatibility, which translates into optimal adaptation to soft tissues. It has low plaque retention and proliferation when its surface has been polished [36].

In terms of translucency, it is 30% higher compared to zirconia. Whereas zirconia-reinforced lithium silicate (12.36 ± 0.42) has a higher opalescence [37]. However, the presence of silica confers acid sensitivity, resulting in high bond strength to the substrate, through both micromechanical and chemical bonding mechanisms [38].

The minimum thicknesses of the crown preparation according to the study protocol in various areas are 1 mm on the occlusal or incisal surfaces, on the labial or buccal surfaces, on the proximal and lingual surfaces when it is adhesive cementation and 1.5 - 2 mm in ionomer cementation respectively to improve its adhesion [39].

The surface should be etched with 9% hydrofluoric acid for 40 to 60 seconds, rinsed with water and etched again with 37% phosphoric acid for 1 minute to remove fluorosilicate deposits and a silane coupling agent for 2 to 3 minutes to remove some of the glass matrix [40]. Because this is a chemical and mechanical bonding, avoid sandblasting as it causes micro fractures [41].

3.4. Alumina

Alumina, or aluminum oxide (Al2O3), is a chemically inert ceramic with clinical applications based on its biocompatibility, density, hardness and wear resistance. Pure alumina has a strength of ~410 MPa [36].

According to the systematic review study by Pjetursson *et al.*®, all-ceramic FDPs and glass-infiltrated alumina had a 5-year survival rate of 86.2%, which was lower than the rates for densely sintered zirconia (90.4%) and reinforced glass-ceramic (89.1%) [42].

Framework fracture occurs frequently when glass-infiltrated alumina is used as posterior restorations and when the connector diameter is smaller than 4 mm X 4 mm.®S Chen *et al.** reported a higher frequency of framework fracture in RBFDPs fabricated from glass-ceramics as silicate and infiltrated alumina; they have low flexural strength and therefore require larger connectors [43].

Air abrasion of the surface of zirconia-based dental ceramics with alumina particles increases the fracture toughness of zirconia veneers and the monoclinic phase volume. This increase is strongly related to alumina particle size [44]. The alumina particle sizes currently in use are 29 µm and 53 µm (nominal). Both particle sizes exceed the FDA (Food and Drug Administration) lower exposure limit of 10 µm [45].

4. Conclusion

Zirconia is a ceramic material widely valued in restorative dentistry for its remarkable mechanical resistance, especially against occlusal loads, which positions it as an excellent option when functionality is prioritized, although its esthetic performance is inferior to that of other ceramics; however, by means of specific techniques, it can achieve acceptable results in visual terms. Porcelain, classified as a vitreous ceramic, stands out for its high esthetics derived from its vitreous phase, satisfying high demands in appearance, although its structural resistance is still optimized through the incorporation of material reinforcements. Silicates stand out for their adequate flexural strength, ability to prevent fractures, remarkable translucency and low microbial adhesion, qualities that make them especially attractive for esthetic restorations. In contrast, alumina has been practically displaced from clinical use in dental restorations due to its mechanical and esthetic limitations compared to more advanced alternatives, remaining in use only in applications as an abrasive material.

4.1 Conflict of Interest

Not available.

4.2 Financial Support

Not available.

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