INFLUENCE OF YTRIO PERCENTAGE ON MONOLITHIC ZIRCONIA PROPERTIES: LITERATURE REVIEW

INFLUÊNCIA DO PERCENTUAL DE ÍTRIO NAS PROPRIEDADES DA ZIRCÔNIA MONOLÍTICA: REVISÃO DE LITERATURA

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ABSTRACT

The fundamental disadvantage of conventional zirconia is its high opacity. Depending on different conditions, especially on the content of the yttrium stabilizer, it is possible to circumvent this issue. Thus, numerous generations of yttrium-stabilized zirconia have been developed seeking to combine the robustness of zirconia with the esthetics of porcelain veneers. This study aimed to analyze how the increase or reduction of the percentage of yttrium in the composition of monolithic zirconia can influence their properties, especially regarding translucency. This study was carried out through a review in the SciELO, PubMed, and Google Scholar databases, with papers published between 2013 and 2021. Hence, we concluded that the higher Y2O3 content tended to increase the amount of isotropic cubic phase present and reduce the amount of birefringent tetragonal phase in ZrO2, along with minimization of light scattering by secondary phases, leading to increased translucency and aging resistance. As yttrium oxide increases, the sizes of the zirconia grains tend to increase as well. Toughness and fracture resistance may be considerably sacrificed.

Keywords: Yttrium; Zirconium; Ceramics; Dental Prosthesis; Dental Porcelain; Dental Materials.

RESUMO

A principal desvantagem da zircônia convencional é sua alta opacidade. Dependendo de diversas condições, especialmente o conteúdo do estabilizador ítrio, é possível contornar essa questão. Em vista disso, várias gerações de zircônia estabilizada com ítrio foram desenvolvidas buscando aliar a robustez da zircônia com a estética das facetas em porcelana. O presente trabalho teve como objetivo realizar uma análise a respeito de como o aumento ou a redução do percentual de ítrio na composição das zircônias monolíticas podem influenciar em suas propriedades, sobretudo no que tange à translucidez. Este estudo foi executado através de uma revisão nas bases de dados SciELO, PubMed e Google Scholar, com artigos publicados entre 2013 e 2021. Desse modo, concluiu-se que o maior teor de Y2O3 tendeu a aumentar a quantidade de fase cúbica isotrópica presente e reduzir a quantidade de fase tetragonal birrefringente no ZrO2, juntamente com uma minimização da dispersão de luz por fases secundárias, levando ao aumento da translucidez e resistência ao envelhecimento. À medida que o óxido de ítrio aumenta, os tamanhos dos grãos de zircônia tendem a aumentar também. A tenacidade e a resistência à fratura podem ser consideravelmente sacrificadas.

Palavras-chave: Ítrio; Zircônio; Cerâmica; Prótese dentária; Porcelana dentária; Materiais dentários.

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INTRODUCTION

In dentistry, restorative and prosthetic techniques aim to reestablish the masticatory function and natural esthetics. These techniques have been developed further, constantly aiming at the improvement of the means and materials employed, especially due to the increasing esthetic demand in contemporary society (1). A beautiful and harmonic clinical result depends on the marginal integrity, surface characterization, and anatomy, in addition to the final compatibility of the colors when compared to the original teeth, which is closely related to optical characteristics such as translucency. The latter is considered one of the most important determining factors of esthetics in dentistry (2).

In this scenario, ceramics are displayed as an exceptional alternative in the reproduction and mimicking of enamel and dentin (2). They present good biocompatibility, thermal expansion coefficient close to that of the tooth, they are non-reactive and have good satisfying resistance to abrasion and compression, in addition to a high degree of intraoral stability, characteristics that grant longevity and safety in restorative works (3,4,5,2). As for their composition, the ceramics may be glassy, infiltrated, and polycrystalline (crystalline) (2).

Zirconia, a polycrystalline ceramic, has been highlighted in its current market for its significant advantages, such as mechanical properties that are superior to other ceramic systems, radiopacity, low corrosion potential, chemical inertia, volumetric stability, and elasticity modulus values comparable to those of steel (6,2,7). Additionally, its characteristic milky white color, high opacity, biocompatibility, and mechanical attributes superior to those of metal alloys, lead them to be used as a substitute material for metals in the infrastructures of ceramic prostheses, implant structures, crowns, and fixed dental prostheses (8,9,10,11).

As for its use in infrastructures (i.e., in two-layer restoration, consisting of the zirconia core or structure covered by a vitro-ceramic veneer that provides the necessary color and optical characteristics), the laminate-core bond strength is considered low and can be led to delamination and fracture of the material, which is clearly a disadvantage (5). Regarding monolithic restoration (full contour), it is composed of only one ceramic piece that can be stained when necessary and is commonly used in posterior and in high occlusal loads regions. The esthetic result may be inferior when compared to the bilayer one, but its mechanical properties are superior (5). Zirconia (ZrO2) has been pointed as the first choice for monolithic restorations of complete contour, as it provides a less invasive preparation of dental tissues since its mechanical superiority allows the production of pieces with less thickness and only one layer (12,7).

The core structures and monolithic zirconia pieces are manufactured through computer-assisted design and manufacturing technology system CAD/CAM (computer-assisted design/computer-assisted machining), milling commercially available blocks, which are usually pre-sintered (7). Zirconia is the advanced ceramic that displays the best mechanical performance for dental use and machining with the CAD/CAM system (13). Hence, the advent of this technology resulted in greater ease of customized and automated processing, making production faster, and simpler, and boosting its popularity (8,14,10).

The number of crystals in the glass matrix is said to directly influence the translucence of the ceramic: the greater the number of crystals in the glass matrix, the lower the ceramic's translucence, and the fewer infiltrated particles, the greater the translucence (2). Conventional monolithic zirconia (3Y-TZP) has atoms arranged in an essentially crystalline, regular arrangement, with grain contours and crystallographic conformations that are centers of light scattering and alter the optical properties, making them highly opaque (i.e., with a very low translucence) (15,14).

Consequently, the main disadvantage of conventional zirconia is its high opacity. Depending on the sintering conditions, some factors such as grain size, density, additives, and especially the content of the yttrium stabilizer may circumvent this issue. Thus, various generations of zirconia stabilized with yttrium were developed, aiming to combine the robustness of zirconia with the esthetics of porcelain veneers, in addition to contributing to better efficiency in the polymerization of resin cement with greater translucency, increasing clinical applicability, and preserving dental structure with less thickness requirement (16,17).

The first yttrium stabilized zirconia (Y-TZP) that was marketed had a 3 mol% yttrium oxide composition (3Y-TZP). Nowadays, there are commercial zirconia for dentistry with percentages of yttrium ranging from 3 to 5% (e.g., 4Y-TZP and 5Y-TZP, which are more translucent), revealing that the addition or reduction of the percentage of yttrium plays a significant influence on the final properties of the piece (8,9,10,18,19).

Thus, this study aims to review the literature to analyze how the alteration of the percentage of yttrium in monolithic zirconia may influence their properties, especially concerning translucency.

LITERATURE REVIEW

This study was performed, initially, through an integrative review in the SciELO and PubMed databases. The following keywords were used in conjunction: (Yttrium or *Ítrio*), (Zirconium or *Zircônio*), (Ceramics or *Cerâmica*), (Dental Prosthesis or *Prótese Dentária*), (Dental Porcelain or *Porcelana Dentária*), and (Dental Materials or *Materiais Dentários*), both in English and Brazilian Portuguese, for all the articles related to the subject to be found. Subsequently, a complementary search was performed using the keyword "Yttrium" on Google Scholar. A total number of 42 papers were found, of which 30 were included and 12 were excluded. Inclusion criteria included articles published between 2013 and 2021, *in vitro* studies, clinical trials, and literature reviews. Papers that preceded 2013, in addition to those that did not address the objective of the study, were factors used as exclusion criteria.

Zirconia

Zirconia is the 18th most abundant element in the Earth's crust, existing in a pure state in the amorphous (a bluish black powder) and crystalline (a white and ductile metal) forms (2). Zirconia-based polycrystalline ceramics may be classified according to their microstructure into three types: FSZ (fully stabilized zirconia), PSZ (partially stabilized zirconia), and TZP (tetragonal zirconia polycrystals). The most used in dentistry is TZP, and it is predominantly composed of the tetragonal phase (t), metastable and stabilized with yttrium oxide (3-6% in weight), giving rise to Y-TZP (tetragonal zirconia stabilized with yttria) (20). It can assume three crystallographic phases according to temperature: monoclinic (room temperature up to 1170ºC), tetragonal (t) (between 1170ºC and 2370ºC), and cubic (c) (when the temperature is above 2370ºC to the melting point) (20,21). Pure zirconia is monoclinic at room temperature and this phase is table up to 1170ºC. Above that, in the tetragonal phase, it depends on stabilizers; in the cubic phase, it is only stable at very high temperatures (22).

When this stabilized material is subjected to stresses (e.g., chewing, wearing, and polishing), a transformation from the tetragonal to monoclinic phase may occur, accompanied by an increase in volume. The monoclinic form (m) occupies a volume of 3 to 5% greater than the tetragonal grains, resulting in a generation of compression and nucleation stresses of microcracks (microcrack toughening) around the defect, preventing the crack from propagating and leading to the material's fracture. This mechanism, known as "transformation toughening," is mainly responsible for the fact that Y-TZP is the dental ceramic that presents the best mechanical properties (20,1).

Another toughening mechanism occurs due to the formation of microcracks that arise after local volumetric expansion in the transformation of the tetragonal to monoclinic phase. In this case, the voltage generated by the volumetric expansion exceeds the value supported by the elastic regime of the material, and microcracks arise around the transformed region. These microcracks serve as deflectors and crack branches that are propagate in the material (8,23).

3Y-TZP ceramics have also been shown to be susceptible to progressive chemical aging, termed low-temperature degradation (low-temperature degradation - LTD), which can occur in the presence of water at room temperature. The process involves the penetration of water into surface microcracks, inducing a reversal of the metastable zirconia t-phase back to its most stable m-phase. These reversions cause local peeling stresses, further driving the microcracks and transferring deeper internal stresses underground, grain by grain. Microcracks coalesce and lead to the detachment of the grains, with consequent degradation of resistance (24,25). Zirconia with higher c content is less susceptible to aging, as this phase does not undergo transformation (26,27).

The doping agent is an oxide and acts as a grain contour engineering tool that has control over the composition of ZrO2 grain contours (14). Stabilizers or doping agents are added to aid sintering and control transformability, and directly influence material properties (27). Thus, many components are added for stabilization of the metastable tetragonal phase at room temperature, such as calcium oxide (CaO), magnesium oxide (MgO), lanthanum oxide (La2O3), cerium oxide (CeO2), and, especially, yttrium oxide (Y2O3) (22,1).

Yttrium

Yttrium (Y) and its compounds originate from the chemical processing of ores, in which the presence of lanthanide elements is large, known as rare earths. It is a metallic chemical element, its atomic number is 39, and it has an atomic mass of 88.90584u; it is soft, silvery, solid at room temperature, and of triatomic character, which contributes to the presence of several charge-neutralizing oxygen vacancies (10,7).

RESULTS AND DISCUSSION

Influence of Yttrium

As the content of yttrium oxide increases, the amount of isotropic cubic phase—optically homogeneous, in which the refractive index is constant despite direction, i.e., the light ray propagates with the same speed in all directions—increases in grain contours, which can lead to a decrease in birefringence (optical property of a material that has different refractive indexes for different directions of light propagation) (18).

According to Zhang *et al*., the most studied method for bettering zirconia translucency is to increase the yttria content, introducing a more isotropic cubic phase and less birefringent tetragonal phase, along with minimization of light scattering by secondary phases, such as alumina particles and porosities (12).

Accordingly, Zhang *et al*., when evaluating optical, mechanical, and stability properties of yttrium-stabilized zirconia with different compositions, concluded that the introduction of optically isotropic cubic phase zirconia (cubic phase is stable and does not undergo stress toughening), along with the increase of the yttria content (5 mol% in this study), showed the best effect to increase translucency as well as aging resistance on 3Y-TZP ceramics (25). Toughness and fracture resistance, however, were considerably sacrificed.

Zhang and Lawn, when discussing the tendency of using a higher yttria content to produce partially stabilized zirconia, 4 mol% (4Y PSZ) or 5 mol% (5Y-PSZ), with increased amounts of non-birefringent cubic phase, deduce that even though translucency has improved, resistance and toughness were decreased because cubic zirconia does not undergo voltage-induced transformation (26).

In their review, Pekkan *et al*., when evaluating the factors that affect the translucence of monolithic Y-TZP ceramics, found that the higher Y2O3 content tended to increase the amount of cubic phase present in ZrO2 and concluded that a combination of the fine grain size and cubic ZrO2, with an isotropic refractive index (which helps to avoid the dispersion of grain contours), produces improved translucence (14).

In his thesis, Fonseca (2019) stated that the higher amount of yttrium in zirconia causes the stabilization of the cubic phase at room temperature, which results in a decrease in mechanical resistance and increased translucency of the material due to the optical isotropy of this phase (8).

Shin and Lee, in their work, when comparing the surface roughness between dental zirconia with different yttrium oxide compositions under the same polishing conditions, observed that, as the composition of yttrium oxide increased, the sizes of the zirconia grains tended to increase. Thus, they stated that translucency can be improved by increasing the grain size; nonetheless, it was found that the increase in the composition of yttrium oxide can lead to a decline in the composition of the tetragonal phase of the surface, which has the potential to harden by transformation, and as a result, the mechanical properties of zirconia would be impaired (18).

Kontonasaki *et al*., in turn, point out in their study that the general trend is that, as the sintering temperature increases, the translucency and grain size also increase. Therefore, in zirconia core ceramics, in which an increase in sintering temperature can cause a decrease in flexural strength, this decrease is attributed to a probable migration of yttrium to the grain contours (7).

Pereira *et al*. attribute the higher stabilizer content yttrium the responsibility for the high resistance to aging and for eliminating the zirconia transformation hardening mechanism, in addition to being responsible for the appearance of a large number of cubic crystals in its microstructure. They also estimate that the higher the temperature for sintering and the higher the yttrium content, the larger the size of crystalline grains (28).

For Harada *et al*., the increase in yttrium concentrations tends to increase the amount of optically isotropic cubic phases. Cubical grains are normally bigger than tetragonal grains, resulting in fewer grain limits. Light transmission through polycrystalline ceramics is strongly affected by birefringence at the grain border; therefore, the lower amount of verges between the grains leads to increased translucency (29).

In the study conducted by Pandoleon *et al*., on yttrium depletion in zirconia aging, there was a significant decrease in yttrium content after aging for 5 and 10 h, suggesting that yttrium is removed and that its depletion occurs during the transformation t-m with aging in water vapor. Moreover, a high luminescence was observed by the high amount of oxygen vacancies. Thus, the transformation of the t-m phase after aging with significant loss of yttrium resulted in a decrease in oxygen vacancies and reduced luminescence. Surface oxygen vacancies migrated in and involved ZrO2 oxygen, constituting a metal phase of Y2O3 on the surface after aging. Accordingly, the number of oxygen vacancies generated can act as point defects that absorb light, impairing the optical behavior and translucency of the material (30).

Studies directly addressing the correlation between the percentage of yttrium in the composition of zirconia and its final properties are scarce in the literature. Laboratory research, as well as clinical trials seeking to describe what to expect from prosthetic pieces with a higher or lower percentage of this component, advantages and disadvantages of increased translucency, and how this change can interfere with the characteristics of abrasion, mechanical resistance, and fracture toughness, would be of fundamental importance for this line of research.

CONCLUSION

The papers analyzed in this study point in the same direction by agreeing that the percentage of yttrium has a significant influence on the properties of monolithic zirconia. Thereby, the higher Y2O3 content tended to increase the amount of isotropic cubic phase and reduce the amount of birefringent tetragonal phase in ZrO2, along with minimization of light scattering by secondary phases, leading to increased translucency and aging resistance. It was also found that, as yttrium oxide increases, the sizes of zirconia grains tend to increase as well, and there may be an improvement in translucency; though, toughness and fracture resistance may be considerably sacrificed.

The authors declare no conflicts of interest.

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