Physical and Chemical Conditions for the Long-Term Functioning of Restorations with a Zirconia Framework

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Abstract

The aim of the study is to determine the optimal physico-chemical conditions and factors for the long-term perspective of zirconia-based restorations.

Information was searched in English without time limits in the PubMed electronic database, a Google search and literature lists of relevant studies and reviews. Full-text articles from 2003 to 2018 were selected, in which studies of frameworks made of zirconium dioxide, a protocol for changing firing temperatures, and a description of the structure are described.

Totally 79 articles were identified. After the selection of articles on the inclusion criteria and removal of duplicate articles, the total number was 5. The review of the literature included studies of 3 types of zirconium: "3Y-TZP", "ATZ", 12Ce-TZP". In a number of studies, the authors studied experimentally the influence of the oral environment on the long-term functioning of zirconium, and a number of authors conducted a study on the effect of heating and cooling gradients, as well as mechanical processing of zirconium frameworks.

This literature review has shown the optimal physicochemical conditions and factors for the long-term prospects for restorations with a zirconia-based framework, starting from its composition, technical and laboratory stages, and pumping over the oral cavity factors. The combination of these factors can reduce the effect of the transition of zirconium dioxide from the tetragonal to the monoclinic phase, as well as reduce the stress outcomes resulting from the processing of zirconia frameworks and their facing layer.

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Introduction

Zirconium in dentistry is used as a material for the manufacture of crowns, abutments and orthodontic braces[1-3]. It is also used in all ceramic restorations as a framework (Figure 1) due to its biocompatibility, high strength and aesthetics[4-6].

Zirconium is a polymorphic material that exists in three crystalline structures: monoclinic, tetragonal, and cubic[7]. In its pure form, zirconia presents the monoclinic phase in the temperature range from room temperature to 1170 ° C. It passes into the tetragonal phase in the condition above this temperature. At a temperature of 2370 ° C zirconium dioxide turns into a cubic phase[7,8].

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Figure 1. CAD/CAM milled zirconium bridge framework.

Stages such as grinding and sandblasting can initiate the tetragonal transformation into the monoclinic phase[9,10]. This transformation is accompanied by an expansion in the volume of zirconium from 3% to 4% [11,12]. This feature increases the risk of a framework fracture during its functioning in the oral cavity[8].

In addition, the transition from the tetragonal to the monoclinic phase can also be inadvertently induced due to hydrothermal oxidation in moist conditions of oral cavity[13,14].

The presence of hydrothermal stress caused by water, blood and synovial fluids over a long period of time is considered to be unfavorable, since it causes micro- and macrocracks, reducing the mechanical properties of zirconium frames. This phenomenon is called low temperature degradation or aging[9].

Zirconium framework is protected from aging due to lining; however, it has been shown that conventional fixation cements absorb water through the dentin tubules, thereby exposing zirconia to moisture, which in turn can lead to aging problems for a shorter period of time[17].

The tetragonal phase of zirconia can be maintained at room temperature by adding a number of oxides. For dental purposes, more often polycrystals of tetragonal zirconium are usually stabilized by 3 mol. % Yttrium (3Y-TZP) [7].

Residual stresses can appear during the firing process and have two main origins: due to the mismatch between thermal expansion and temperature stresses associated with temperature gradients during cooling[15,16].

The aim of this literature review is to determine the optimal physicochemical conditions and factors for the long-term prospects of restorations with a zirconia-based framework.

Materials and methods

Search strategy.
Search in English without time limits was performed by four independent people in the PubMed electronic database. In addition to electronic databases, other sources were also used to search for relevant information on the topic. These include a Google search and reference lists of relevant studies and reviews.

Inclusion and exclusion criteria.
Publications matching the following selection criteria have been included:
1. Full-text articles from 2004 to 2019.
2. Studies of frameworks made of zirconia.
3. Studies include a protocol for changing firing temperatures, as well as a description of the structure.

Not related publications, clinical cases, and articles that did not have enough data for analysis were excluded.

Article selection.
Studies were filtered and selected in several stages. First, articles published before 2004 have been excluded. Secondly, publications were rated by title. Thirdly, all publications were evaluated by reviewing full-text and abstract articles. At each stage, the researchers worked independently. The difference in choice was resolved through discussion. (Figure 2).

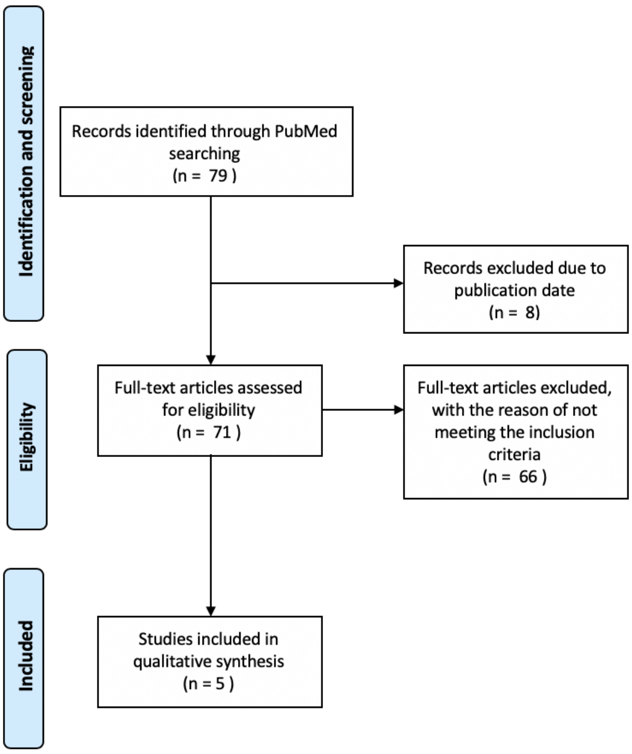

Figure 2. The flow chart of the article selection for the literature review

Results

A total of 79 articles were identified. After selecting the articles according to the criteria for including and deleting duplicate articles, the total number became 5 (Table 1).

Author	Year	Aim
Kohorst et al. [18]	2011	Determination of the effect of simulated aging on the transformation of the tetragonal-monoclinic phase and on the flexural strength of 3Y-TZP ceramics compared with aluminized zirconia (ATZ) and stabilized zirconia (12Ce-TZP).
Tholey et al. [19]	2011	Comparison of temperature gradients during fast and slow cooling for conventional and anatomical structures, as well as an optical procedure for direct comparison of the effect of cooling rate on residual stresses.
Alghazzawi et al. [20]	2011	Investigation of the effect of manufacturing restoration procedures on low temperature modeling and relative changes in bending strength, nanoindentation hardness, Young's modulus, surface roughness and structural stability of yttrium oxide stabilized zirconia.
Hatanaka et al. [21]	2016	Assessment of changes in microstructural and crystallographic phases, flexural strength and Weibull modulus of 3Y-TZP zirconium after grinding with water cooling and without regenerative firing.
Henriques et al. [22]	2016	Assessment of the effect of structural design variables (composition and layer thickness) on residual stresses in alumina and zirconium oxide.

Table 1. Brief information on the articles included in the literature review.

Author	Zirconium type	Max t°	Min t°	t° - changing protocols	Physical outcomes
Kohorst et al. [18]	3Y-TZP	134 ° C	N/A	Slow increase of the temperature to 134 ° C	Bending strength before aging - 1740 MPa, after -1169 MPa
Kohorst et al. [18]	ATZ	134 ° C	N/A	Slow rise in temperature to 134 ° C	Bending strength before aging - 1093 MPa, after -1378 MPa
Kohorst et al. [18]	12Ce-TZP	134 ° C	N/A	Slow rise in temperature to 134 ° C	Bending strength before aging - 495 MPa, after -480 MPa
Tholey et al. [19]	Y-TZP	530 ° C	900 ° C.	Temperature gradients that occur at temperatures above the glass transition temperature of porcelain during cooling	The maximum temperature differences inside and outside are present in the areas of MP2, MP3 and MP8
Alghazzawi et al. [20]	Y-TZP	1530 ° C	900 ° C	Heat changes in the temperature range from 900 ° C to 1000 ° C.	Reverse conversion from monoclinic to tetragonal after aging, grinding or sandblasting of Y-TZP.
Hatanaka et al. [21]	3Y-TZP	1000 ° C	Room temperature	Annealing zirconia at 1100 ° C for 30 minutes	The bending strength of zirconium after firing can be explained by the interaction of the antiphase transformation and the "healing" of cracks.
Henriques et al. [22]	Y-TZP	500 ° C	25 ° C	At the beginning of the simulation, the recovery does not cause stress, and its temperature is uniform at 773.15 K (500 ° C). Then, the temperature on the restoration walls decreases with a constant cooling rate from the initial temperature to 273.15 K (20 ° C) for 950 s, at a constant cooling rate of 0.5 K / s.	Modeling showed three different spots of increasing concentration: in the inner part of the frame; on the border between the frame and the intermediate layer; and at the junction between the layer and the veneer.
Tholey et al. [19]	Y-TZP	1530 ° C	600°C	Heating for two hours. Fast and slow cooling was performed.	The largest temperature differences and the associated thermal stresses occurred in the cladding area, where crown chipping is often observed.

Table 2. Information on the study protocols. N/A – not available.

The literature review included studies of 3 types of zirconium: “3Y-TZP”, “ATZ”, 12Ce-TZP ”.

Some works studied experimentally the effect of the environment of the oral cavity on the long-term functioning of zirconium[18, 20]. Tholey et al.[19] and Hatanaka et al.[21] investigated the influence of technical protocols, such as heating and cooling gradients, as well as the mechanical processing of zirconium frameworks. Henriques et al. [22] evaluated the influence of design features (composition and layer thickness) on residual stresses.

More detailed information on the aims, results and protocols used in the studies of these authors are presented in Tables 1 and 2.

Discussion

More recently, the advent of ceramic systems in dentistry, in particular, with a zirconia-based skeleton, has helped improve the aesthetics of ceramic restorations[23,41]. Alumina was also used in all ceramic restorations as a framework because of its biocompatibility, high strength, and aesthetics[23–26], however, it was shown that zirconia-based restorations have significantly higher residual thermal stresses than restorations on alumina based[22]. This is due to the higher heat capacity and density of zirconium dioxide[27].

Grinding is a standard procedure in clinical practice and is used to achieve the best fit between the zirconia framework and the tooth, as well as to obtain sufficient space for applying the veneering layer[28-33]. Grinding can create surface defects, such as cracks, as shown by Hatanaka et al.[21], in addition to grooves and micro-fractures, depending on the size of diamond chips, the strength and speed of work with it[34-37]. These cracks can spread to the bulk of the material, reducing its bending strength[33,38]. Therefore, any grinding of zirconia frames should be performed with water cooling[21].

The firing of zirconia frameworks does not substantially change its bending strength, as some authors noted[38,39]. However, Ho et al.[40] found that firing zirconia at 1100 ° C for 2 hours can reduce crack growth. Hatanaka et al.[21] proved that before applying the facing layer, it is necessary to calcine at 1500 ° C in order to obtain a more reliable result.

Tholey et al.[19] showed that slow cooling, in comparison with the usual cooling procedure, temperature gradients can be minimized through the veneering layer. The results clearly showed the stresses arising from the mismatch of the coefficient of thermal expansion. Therefore, an elementary change in the cooling protocol will also lead to a clear decrease in the residual stresses caused by the thermal gradient, which are one of the possible causes of cracking. Until 2009, it was recommended that the cooling of the veneering be carried out to 850 ° C, however, this study showed the advantages of the long-term functioning of the zirconium dioxide framework, with slow cooling of its veneering to 600 ° C.

As for the veneering layer, which is applied to the carcass from zirconium dioxide, its presence can significantly reduce the thermal residual stress at the interface between the layers and at points of stress concentration [22]. Both the composition and the thickness of the intermediate layer have a great influence on the residual thermal stresses. The optimal thickness of the intermediate layer is in the range of 30-50% of the entire ceramic cladding, which balances the stress in the frame and at its borders. Stresses decrease with increasing thickness of the intermediate layer[22].

To stabilize the tetragonal phase, which is larger on the surface, and significantly increase its roughness[20], small amounts of oxides of other metals, such as Y_2O_3, MgO, CeO, or CaO, are added to zirconium[9,10]. In the early phase of aging under hydrothermal conditions, yttrium-stabilized zirconium oxide is extremely susceptible to low-temperature degradation[18]. Zirconia stabilized by Cerium, although not affected by hydrothermal aging, can only be considered for the manufacture of heavily loaded dental restorations[18]. From the point of view of strength, the most promising restorations are restorations with an aluminum oxide framework reinforced with zirconium[18,22], which makes these restorations the most favorable for use in a hydrothermal environment of the oral cavity.

Conclusions

Thus, this literature review showed the optimal physicochemical conditions and factors for the long-term prospects of restorations with a zirconia-based framework starting from its composition, technical and laboratory stages, and pumping it through overcoming the factors of the oral cavity. The combination of these factors can reduce the effect of the transition of zirconia from the tetragonal to the monoclinic phase, as well as reduce stress outcomes resulting from the processing of zirconium frames and their veneering layer.

Declaration of Interest

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