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RESEARCH ARTICLE

LONGEVITY OF ZIRCONIA FRAMEWORKS

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ABSTRACT

A metal-free dentistry has long been the dream of all practitioners. However, the inherent fragility, low flexural strength, as well as the low fracture resistance of ceramics were the main obstacles slowing the use of these materials. To overcome this weakness, researchers and manufacturers have developed advanced formulas to prevent the propagation of cracks in the ceramic using mainly yttria-tetragonal zirconia polycrystal (Y-TZP), commonly known as "zirconia". However, despite their resistance to mechanical tests, zirconia frameworks can still be fragile if their properties are not well studied, and the requirements for handling them are not met. To succeed zirconia frameworks, several requirements need to be known, respected and applied.

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INTRODUCTION

Dental ceramics, initially used only for their esthetic merits, developed into more resistant and crystalline materials. The objective of this development is to be able to use ceramics as infrastructure materials as well, replacing metal alloys. The combination of professional skills and innovations in biomaterials have brought on stage zirconia in the early 1990s. (Lebras, 2003; Akgungor *et al*., 2008) Today, the zirconia frameworks represent a prosthetic solution through its various structural properties and characteristics. However, this material requires demanding indications and careful use, both for the clinician as well as the laboratory technician. In this work, we study the properties of the zirconia framework as far as their longevity is concerned.

Presentation of zirconia frameworks

ZrO_2 zirconium dioxide, which is more commonly called "zirconia" is a metal oxide obtained from a chemical reaction of zirconium oxidation. It is a ceramic represented by the following formula $Zr + 02 = ZrO_2$ Zirconium dioxide (ZrO_2) has at ambient pressure and depending on temperature three crystalline phases (Fig 1). The stresses generated by these structural changes generate cracks in the volume of pure zirconia, which can thus be fractured at ambient temperature.

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Therefore, zirconia for dental purposes cannot be used as such. An oxide is added to stabilize an oxide (yttrium oxide, magnesium or cerium). In this zirconia, (essentially zirconia Y-TZP), a micro-crack that spreads under the effect of stress, has its energy dissipated in both the energy required for the transformation of the structure and the energy associated with the increase in volume resulting from this transformation. This increase in volume creates a compressive stress field at the crack tip opposing the spread of the micro-crack until it stops. This results in a reinforced zirconia transformation phase characterized by very high toughness. (Pilathadka *et al*., 2007; Bruno, 2010; Manicone *et al*., 2007) The most popular type of zirconia is currently the Y-TZP (yttria-tetragonal zirconia polycrystal). In fact, one should say Y-TZP-A as it also contains some alumina. This material is the most successful in the field of resistance to fracture. Its composition is made of about 95% zirconia and about 5% of yttrium oxide. Associated with the resistance values at flexion and significant toughness, fracture resistance of the yttria-stabilized zirconia suggests a high likelihood of long-term clinical longevity.

Properties (Mahiat, 2006; Manicone *et al*., 2007; Hauptmann *et al*., 2000)

Compared to other ceramic frameworks, including alumina, zirconia offers much better mechanical properties. The origin of these unique properties is its dense and flawless structure in micro grains (Fig. 2). In fact, observation of a dense microstructure of a zirconia coping, we cannot detect any microporosity or exaggerated grain growth.

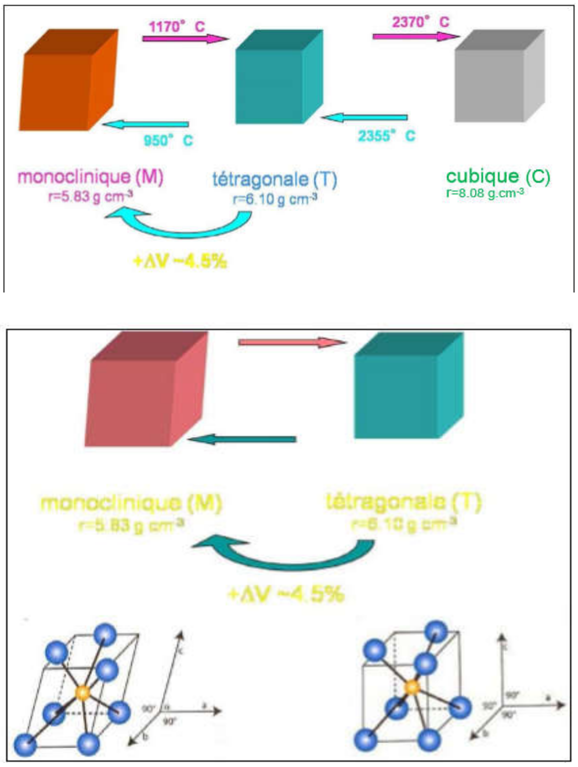


Fig. 1. Schematic representation of the three zirconia phases under atmospheric pressure (Pilathadka *et al*., 2007)

Zirconia is well appreciated for many merits:

- A Relatively low modulus of elasticity (220GPa), allowing it to absorb some of the stresses and thus allows a slight deformation before the fracture.
- An extremely high resistance to flexion.
- The Zirconia has a compressive strength of 2000-2200 MPa, half of that of alumina. Its hardness is 1200 HV also half of the alumina.
- The Process of "resistant transformation" zirconia (or transformation toughening): This is the atypical behavior of volume increase between two phases allowing it to resist the propagation of cracks. This property provides extremely stable and resistant materials making zirconia the toughest ceramic ever.

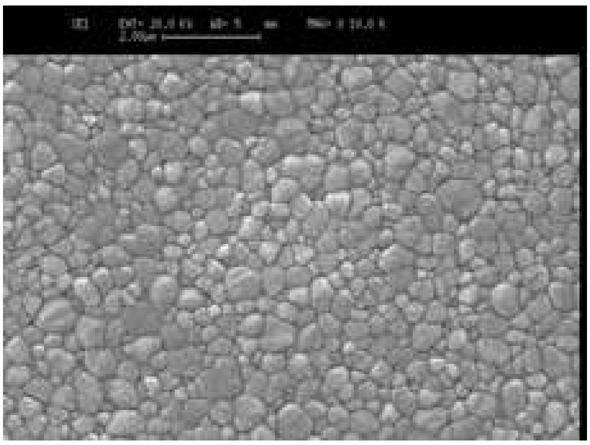


Fig. 2. A flawless and dense structure in micro grains which confers to zirconia its mechanical properties

Longevity of zirconia frameworks

Despite the significant mechanical properties of zirconia, different fracture lines can be observed in the zirconia-supported restorations (Fig. 3). In the case of zirconia frameworks (dense and resistant frameworks and coated with a less resistant veneering ceramic, the crack starts in the veneering ceramic or the interface (Fig. 4). The fragility of zirconia-supported restorations lies in the veneering ceramic or in the bonding strength at the interface. (Poitou, 2007; Quinn *et al*., 2005) The study of the origin and path of the fracture takes all its importance to identify the factors enabling or limiting crack propagation along the veneering ceramic / zirconia interface. (Fig. 5)

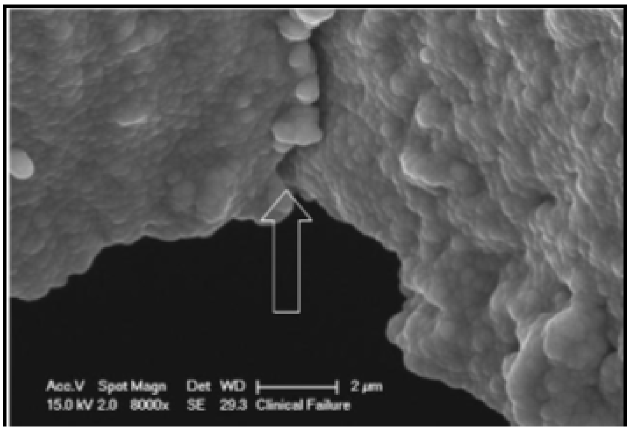


Fig. 3. Image of an electronic microscope (x8000) showing the origin of a radial fissure, in a zirconia framework restoration, Aboushelib *et al*. (2009)

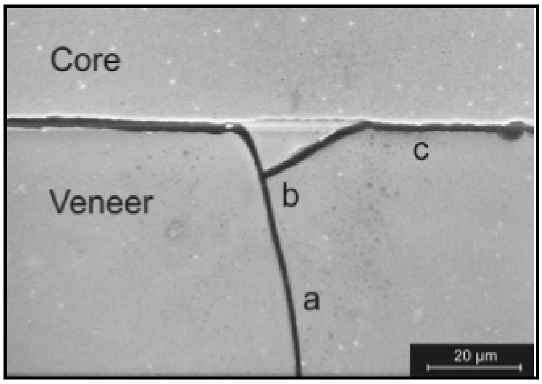
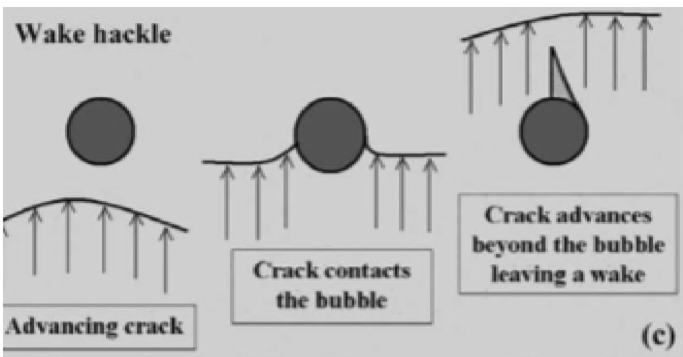


Fig. 4. Image de microscopie électronique montrant la propagation d'une fissure en direction de l'interface (a), bifurcation à proximité de l'interface (b) et propagation le long de l'interface (c), selon Gostemeyer (Gostemeyer *et al*., 2010)



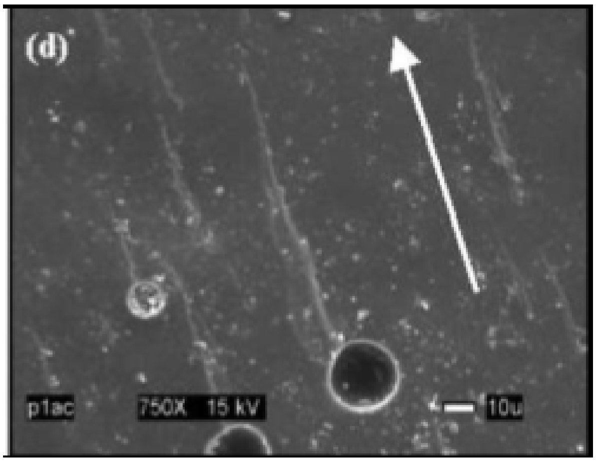


Fig. 5. Mechanism of the formation of fracture lines and the spread of the fissure (Quinn *et al*., 2005)

Examples of study tools (Gostemeyer *et al*., 2010)

There are several ways used to study:

- The various hardness tests (Vickers / Knoop / Hertz / 3 point bending / 4-point bending).
- The method of finite elements. Finite Element Analysis or FEA.
- The Fractography: It is the study of the fractured surface of the ceramic restoration. Indeed, the fractured surface of the ceramic reveals many secrets about the origin of the crack, its management and its progress.

The fracture mode of the zirconia framework (Quinn *et al*., 2005)

This material has a very dense structure with porosities with less than 1% by volume. The bubbles are of small diameter (0,3µm), spherical in shape. The fracture mode is intergranular (Fig. 6) but transgranular. It is the density of the ceramic and the grain size of which determine the intergranular or transgranular path of the crack. (Quinn *et al*., 2005)

The zirconia fatigue

In general, ceramics subjected to repetitive stress undergo a fatigue phenomenon that degrades their mechanical properties over time by progressive and localized structural damage. The decrease in strength is caused by the propagation of cracks under low stress. This degradation is particularly remarkable in ceramic materials having curing mechanisms such as the martensitic transformation in zirconia. (Salazar *et al*., 2010; Tudart *et al*., 2007) Indeed, in the case of yttria-stabilized zirconia framework with, a high concentration of water molecules in the environment increases the crack growth rate by promoting the cleavage of the Zr-O-Zr in the crack tip (Fig. 7). Thus, propagation occurs under review for Kimax = 46% of K IC in an aqueous environment and to 52% of K IC in the air. Therefore, cracks can propagate in that structure although applied forces represent only half of the initial strength. However, faced with this susceptibility to slow crack growth, calculations based on the fatigue parameters and the applied forces indicate that the zirconia infrastructure posterior bridges exhibit longevity rate of over 95% in 20 years provided that the diameter minimum connections is respected. (Fig. 8)

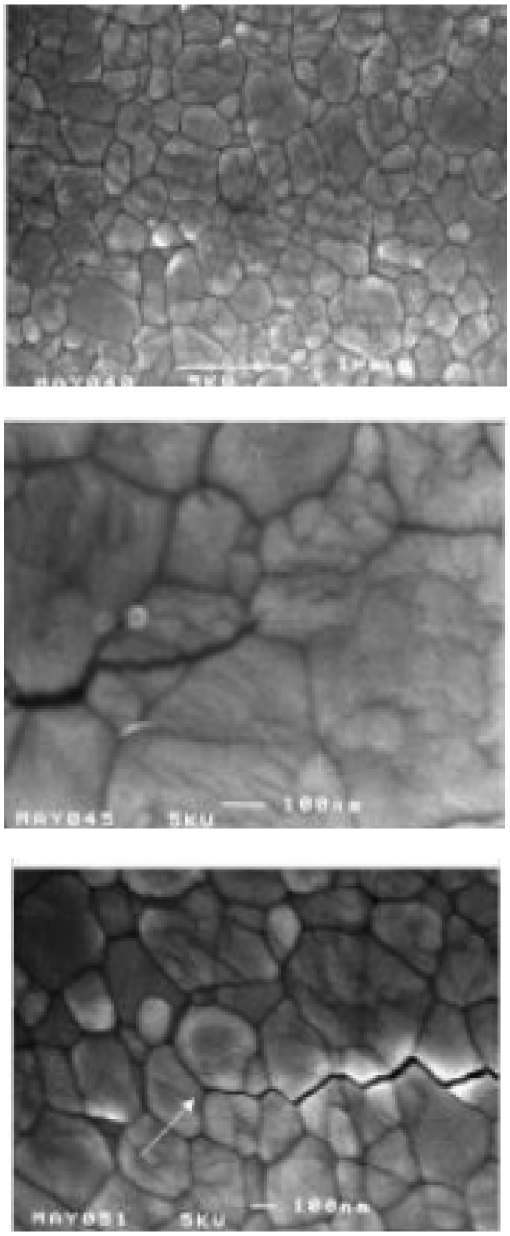


Fig. 6. Analysis of the zircone Y-TZP fissure: The point of fissure is indicated by an arrow, The pattern of fracture is essentialy intergranular, Guazzato *et al.*

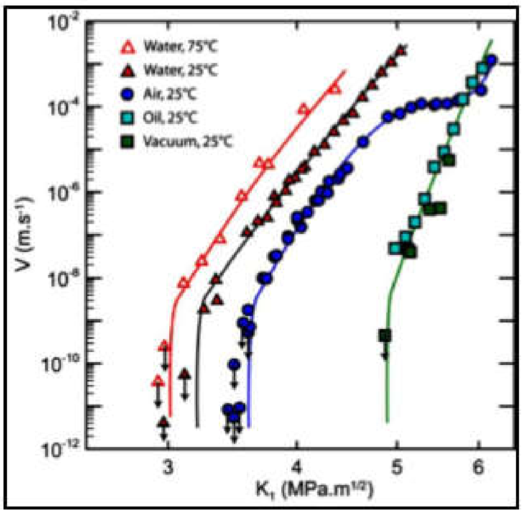


Fig. 7. Effect of the environement on the slow propagation of fissures in, Gremillard (Taskonak *et al*., 2008)

However, the initiation and propagation of a crack is always related to the application of the occlusal force combined with residual stresses in the material. The crack propagation is dependent on the composition of the zirconia, shape, size and orientation of the grains but also the environment, causing the subcritical spread. Thus, the adaptation of these factors will reduce the probability of a crack and the risk of a crack in a zirconia framework.

	Années	% survie	Écaille	nbr réalisations	Auteurs
b 3	5	96,8		65	Eschbach/Kern
b 3 à 5	3	100	4	65	Tinschert
b 3 à 5	10	67		57	Sax et coll.
b 3	5	100		35	Pospiech
b 3	3	100	9	21	Edelhoff
b 3	3	90,5		21	Beuer
b 3 à 4	4	94	12	99	Rodiger
b 3 à 4	4	96	13	24	Wolfart
b 3 à 4 cantilever	4	92		34	Wolfart
b 4	3	100		22	Sturzenegger
b et c	3	98,5		68	Beuer
b 3 à 6	3	90,5	10	21	Edelhoff
b 3 à 7	2	96,6	3	30	Schmitter

Fig. 8. Study of the longevity rates of crowns and bridges on zirconia frameworks (De march and Launois, 2007)

Aging of zirconia: the corollary to its metastability (Le gal and Lauret, 2008; Luangruaangrong *et al.*, 2012; Luthardta *et al.*, 2004)

The metastable zirconia is in its phase of processing capacity. This mechanism has some drawbacks. Indeed, under harsh hydrothermal conditions (temperatures from 200 to 300 °C, humidity), a tetragonal phase transformation can occur spontaneously. This phenomenon evolves from the surface inwards, will gradually spread to reach a deficit monoclinic and critical phase, and ultimately weaken the ceramic which becomes mechanically less resistant. (Luangruaangrong *et al.*, 2012; Luthardta *et al.*, 2004) Moreover, the tetragonal-monoclinic transformation ends up being irreversible. Thus, sanding, grinding which constitute the constraints will transform this material. The aging water produces the same effects, three times faster than at 37 °C ambient temperature. (Luthardta *et al.*, 2004) This phase transformation when it is confined to the vicinity of a crack may occur on the surface of zirconia in contact with water, then being accompanied by an increase in the surface roughness and microcracks. This progressive deterioration called aging is "aging" or degradation at low temperature "Low Temperature Degradation LTD." (Fig. 9) This aging phenomenon is observed especially in orthopedics, but much less in prosthesis, since the zirconia is most often covered with a veneering ceramic protecting this aging due to in vivo functional wear.

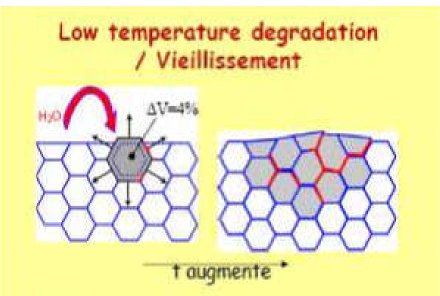


Fig. 9. Different steps in the aging of zirconia under the effect of water (Gremillard *et al.*, 2002)

In conclusion, we can say this strengthening property by phase transformation is an advantage only if it is under control (that is to say, it is triggered when needed). Indeed, it is able to neutralize incipient cracks in the material when exposed to external constraints, such as the occlusal stresses (mechanical reinforcement of the zirconia). The problem occurs when the processing is triggered unintentionally (during milling of the framework) and creates internal stresses which are stored up in the material and affect the stability of the reinforcement zirconia.

Factors affecting the longevity of zirconia frameworks (Raigrodski, 2004; Sailer *et al.*, 2007; Suarez *et al.*, 2004; Vult von steyern, 2005)

Zirconia is the ceramic material (fragile material) the most advanced in terms of resistance to fracture according to Raigrodski, 2004. (Raigrodski, 2004). Four prospective studies have examined the clinical outcome and survival rate of 115 posterior bridges in zirconia, 3 to 5 elements on observation periods not exceeding 3 years. (Sailer *et al.*, 2007).

- The study of SUAREZ (2004) evaluated the In-Ceram Zirconia material (aluminum oxide and 30% zirconia, Al2O3 / MgO), and the other 2 studies SAILER (2007) and VULT VON STEYERN (2005) evaluated the pure zirconia high density (ZrO2 / Y2O3 [3 mol%]) fabricated by CAM machines. (Sailer *et al.*, 2007)

No fracture related zirconia core was observed regardless of the method of manufacturing; the survival rate was calculated from complications such bursts of the veneering ceramic (chipping), secondary caries and loosening; according to studies, the survival rate at 3 years was 84.7% to 95%. A study reported the occurrence of a fracture of a tooth root leading to the loss of the bridge. (Suarez *et al.*, 2004) Fractures more or less important were observed in 15-25% of the restorations. (Sailer *et al*, 2007; Vult Von Steyern, 2005). In one study SAILER *et al*, 15.2% of the restorations had to be replaced due to a high rate of secondary caries and bursting of the veneering ceramic; the authors explain these failures by the lack of realization technique based on real recommendations, unlike other studies using well-standardized CAM systems. Some authors emphasized the elements to be considered in the evaluation of chess: realization by specialists, preparation method including cervical preparation, dimensions critical areas or pillar-intermediate connection area, core design and occlusal form to a support enough for the veneering ceramic. In view of these early studies, the results are promising; Clinical Performance of zirconia for small bridges is greater than that of alumina bridges; However, the rate of fracture of the esthetic ceramic on zirconia remains higher than that of metal ceramic. Faced with these cases of failure, essential criteria for success in developing a bridge infrastructure in Y-TZP zirconia can be highlighted.

Conclusion

The use of innovative materials such as zirconia infrastructure for all-ceramic reconstructions, is a breakthrough in prosthetic dentistry. Its strengths of harmonious color, organic integration with surrounding tissue, as well as its outstanding mechanical qualities and atypical property made by phase transformation, make it the material of the future in esthetic dentistry. However, problems are often encountered with reinforcements zirconia affecting their longevity (especially aging water environment), and that have not been settled prior to marketing. Despite these problems, it will be difficult to return to metal reinforcements. Indeed, the underlying trend and demand of patients going to the biocompatibility and aesthetics. Return to metal reinforcements (better controlled through superior clinical experience) will nevertheless be seen as a regression. It would be better to focus on improving the quality of ceramic plates to us.

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