



# Bonding Mechanism of Porcelain to Frameworks: Similarities and Dissimilarities between Metal and Zirconia

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## Author's contribution

*The sole author designed, analyzed and interpreted and prepared the manuscript.*

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## ABSTRACT

Zirconia restorations emerged as a substitute to metal ceramic restoration, in response to patients' esthetics growing demand. The metal-porcelain bonding mechanism is well known; whereas, the zirconia-porcelain interface is still not fully understood. Several factors have been pointed to explain the high porcelain chipping incidence. This paper will review the latest findings in an attempt to explain the zirconia-porcelain bonding. Peer-reviewed articles published till September 2015 were identified through Pubmed and Elsevier databases. Similarities and differences between metal and zirconia have been raised in the literature.

*Keywords: Zirconia-porcelain interface; bonding mechanism.*

## 1. INTRODUCTION

Different restorative materials are proposed to clinicians. Their reliability depends on the

percentage of restorations still functioning after placement. Different study conditions make the comparison of obtained data challenging. Zirconia frameworks are now widely used by

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dentists. However, some problems and concerns are reported by investigators. This paper will give an overview of the problems encountered. A short mentioning of other all-Ceram systems will help to understand the problems encountered with zirconia-based prosthesis.

For 50 years, porcelain fused to metal (PFM) was the main type of prostheses used in dentistry. Studies reported over 90% success rate for 10 years after placement, either for high-noble or non-precious alloys [1]. The same high success rate is targeted for all-Ceramic frameworks, if they pretend to be as successful as PFM.

An electronic search has been conducted, during September 2015, through PubMed and Elsevier databases. Peer-reviewed articles were targeted. The following key-words have been used: Zirconia, zirconia bonding mechanism, zirconia bonding strength, zirconia porcelain interface. Available full-text articles were read. Related articles were also scrutinized. No hand search was driven.

In-Ceram Alumina was first proposed for crowns and bridges to give natural look appearance. Brittleness and low mechanical stability restricted the material indication to 3-unit bridges only [2]. In-Ceram Alumina was proposed as bridgework for the anterior region, whereas, In-Ceram Zirconia was able to withstand 3-unit posterior bridge occlusal charges [3]. Framework fractures remain the most frequent reported technical failures [3].

Porcelain fused to zirconia prostheses (PFZ) were presented as substitute to PFM restorations, for posterior and multi-unit prostheses. Early failures were rarely reported [4,5]. The fractures observed, mostly involved connectors of multi-units [4] or second molar abutments [6].

Porcelain veneer problems were the most observed complications. Up to 54% cracking with minor loss of material after a short period of 1.2 years after placement have been reported [4]. Material related difficulties were clearly identified [5]. Non-materials factors, namely thickness ratios or framework design may have a role in porcelain cracking. Stresses related to the zirconia-porcelain interface were cited as cause of chipping during function. Surface changes of zirconia may be involved [7].

To bond two materials of different chemical composition and structure is still a challenging

procedure. The veneering porcelain is opposed to metal alloys (gold or non-precious) or to oxide ceramic frameworks. During firing, framework materials (zirconia or metal alloys) keep their crystalline structure, while porcelain cools down as amorphous material, with no long range order in the structure. Each of those materials has different cooling behavior [8].

A phenomenon of diffusive bonding occurs when some atoms from one surface penetrate into the adjacent surface, remaining bounded to its original surface. This mechanism is involved in the fusing of porcelain into metal in the fabrication of metal-ceramic crown. This interaction of atomic species between the two surfaces is related to the time of interaction of the surfaces. The greater the time, the stronger the adhesion. Atoms can also diffuse from one particle to the next during sintering of metal or ceramic to produce a solid mass [9].

## **2. CONSIDERING BONDING BEHAVIOR OF PORCELAIN FUSED TO METAL**

Behavior of metal-porcelain systems is currently well-known. This is not the case of zirconia frameworks [10]. The PFM restorations were first introduced in the late 1950s [11]. Several researches targeted the nature of metal-ceramic liaison. Material preparation, composition as well as application have incurred many developments stages. Test methods to evaluate this interface also evolved, mainly the shear and flexure bond strength tests [11,12].

The Glossary of Prosthodontic terms defines the bond strength as "the force required to break a bonded assembly with failure occurring in or near the adhesive/adherens interface" [13]. Different types of measuring procedures are used for the bond strength, such as shear, tensile, 3-point-bending, and 4-point-bending and so on. The range of values of the shear bond strength for the porcelain alloy bond, vary between 25 to 55 MPa, related to the alloy, porcelain and preparation used [12].

Over the past 50 years, great attention has been paid to build a reliable interface prior to porcelain layering, in the porcelain fused to metal restorations. Attention was also made to the reactions that may enhance the porcelain adhesion to the underlying metallic framework [12]. The metal oxides produced at the surface of non-precious alloys, permit a chemical bond with the porcelain [14]. Mechanical bonding remains a

pillar in a good clinical performance of metal-ceramic prostheses. The keying effect created by  $\text{Al}_2\text{O}_3$  sandblasting provides retention surface for the porcelain.

Different factors contribute to build a strong metal framework / porcelain bond [11,12,15].

### 3. CHEMICAL

Gold-based and palladium-based noble metal casting alloys are known to be corrosion resistant. No stable oxides can be formed at room temperature. Research on gold [16] and high-palladium [17,18] alloys used for ceramic veneering showed high complex structure of oxidized regions. Small amounts of certain base metals (Iron, Tin, indium, Gallium) are incorporated by manufacturers in casting alloy compositions, to form oxides [19]. These oxides contribute to metal-ceramic adherence and chemical bonding. SEM investigations showed that these elements accumulate at the metal-ceramic interface and form an interfacial oxide layer [20].

Metal oxides developed at the surface of non-precious metal framework alloys enable a chemical bond with the porcelain. Nickel and cobalt are the principal elements. They provide corrosion resistance. The chromium oxide surface layer formed blocks the diffusion of oxygen and prevents corrosion of the underlying metal (passivation). This Chromium oxidation provides chemical bonding for porcelain adherence. Titanium oxidation plays this role for titanium casting alloys [21].

An uninterrupted oxide layer should cover the surface to be veneered. A uniform oxide layer is needed to generate a reliable bond. Base-metal alloys form much thicker oxide layers than do noble metal casting alloys. Fracture within the thick oxide layer may occur. This can provoke the failure of the base metal-ceramic restoration. Acid or  $\text{Al}_2\text{O}_3$  particle blasting are used to partially remove the oxide layer [21]. Achieving a successful bond depends largely on a controlled thickness of the metaloxide layer [11,12,15]. High-palladium and other alloys undergo internal (bulk and grain boundary) oxidation in addition to the external oxide layer [21].

### 4. MECHANICAL

A reliable mechanical bond is required to ensure a good clinical performance of metal ceramic

restorations. Sandblasting the metal framework with 100-250  $\mu\text{m}$   $\text{Al}_2\text{O}_3$  to reduce the thick layer of casting oxides is now a standard technique adopted to ensure this requested mechanical bond. The opaque porcelain will flow into the microgrooves created by the sandblasting on the surface of the alloy. The grit blasting will determine the opaque/metal interface. The porcelain can mechanically interlock into the undercuts [11,22].

### 5. COEFFICIENT OF THERMAL EXPANSION (CTE)

After sandblasting and obtaining a homogenous oxide layer, coefficient of thermal expansion (CTE) compatibility between porcelain and alloy is mandatory. Otherwise, generated stresses may disrupt the bond by fracturing or debonding the porcelain [11,12]. The ceramic can no longer undergo viscous flow to relieve thermal incompatibility stresses [21]. The adhesion forces between atoms of different materials induce a thermal expansion mismatch. Residual stress is induced in the bonded joint upon cooling to room temperature, in the case where the framework contracts more than the bonded ceramic [23]. Cooling metal is quicker because it has good thermal conductivity and dissipates heat rapidly. Due to its pure thermal conductivity, porcelain cools more slowly [24,25]. Zirconia has similar poor conductivity as porcelain. This represents the first important difference between zirconia and metallic framework materials [26]. The thermal conductivity of zirconia stays 15 times smaller than that of alumina and around 100 times smaller than that of gold alloys [27,28]. This slow cooling of zirconia retards the balance between the internal and external temperatures. This results in high transitional temperature differences throughout the restoration, at the thicker and irregular layers and especially upon fast cooling. In the fast cooling method, the temperature gradient between the veneering ceramic and zirconia core may reach up to 140°C [29]. This leads to a high residual tensile stress within the porcelain layer and results in high tempering/compressive residual stresses on the surface [30].

Porcelains better support compression than tensile forces. Upon cooling, slight compression is recommended instead of tension [11,12]. During cooling, this can be obtained when the alloy contracts a little more than the porcelain. Many investigations recommended a CTE of the porcelain slightly lower (around 10%) than that of

alloy framework, to guarantee that surface compressive stresses are developed during cooling [22,31]. These coefficients should be closely matched to within approximately  $0.5 \times 10^{-6} \text{ }^\circ\text{C}$  below the glass transition temperature of the porcelain, depending on the cooling rate and the specific product [21].

A secondary bond is also to be mentioned. The van der Waals bond involves weak interatomic attractions such as variations in physical mass or location of electrical charges [13].

## 6. CONSIDERING BONDING BEHAVIOR OF PORCELAIN TO ZIRCONIA

It is not easy to characterize the compatibility of porcelain and zirconia. Standard dilatometer measurements of coefficients of expansion and thermal shock behavior testing of fired crowns are still used by manufacturers during their product development as they are typically used for PFM restorations [6]. A new ISO approved test method has been recently published as draft to determine the bond strength of ceramic-ceramic systems [32].

Different chemical-, mechanical-, and thermal aspects are involved in all-ceramic systems, as for metal-ceramic systems. This will influence the fabrication process and functional reliability of dental zirconia-based restorations.

Like for metal-ceramic, the veneering porcelains provided has a slightly lower CTE than the zirconia [11]. Consequently, if a compatibility issue remains with Yttria Stabilized Zirconia (Y-TZP), it may not be only related to a simple thermal expansion coefficient divergence between the materials. Small mismatch between the CTE of the veneering and Y-TZP is tolerated. This will limit the high residual stresses generated, and will not compromise the bonding interface [33].

Zirconia-porcelain interface may be involved in crazing and chipping during function. Stresses could be related to surface property [34]. Adequate framework design, proper veneering ceramic support and thickness are factors implicated in the ceramic survival [35].

The aggressiveness of silicate glasses as solvents of refractory materials at high temperature is known [36]. Under firing conditions, aluminum oxide is soluble in dental porcelains [37]. Cerium and zirconium

diffuse into a glass used to infiltrate a partially sintered Ce-TZP powder [38]. Lessening of stabilizing dopants (e.g., Y and Ce) might induce local changes in zirconia surface [39]. It results in the destabilization of the *t*-phase [40] with quite high local associated strains [41]. Liquid silicate can penetrate the grain boundaries perhaps similar to water penetration of Y-TZP [34,42,43].

Delamination and chipping of ceramic have been reported. Delamination is defined as a complete debonding of porcelain resulting in exposure of framework. Ohlmann et al. [6] argued that it can only be demonstrated by microscopic examination. It is unfeasible while the restorations are still in situ. This is why, fractures classified as delaminations may be chipping fractures [6]. Only cohesive fractures have been reported within the porcelain, with no debonding from zirconia. The response of the porcelain against occlusal forces is to be considered rather than the bonding of ceramic to zirconia framework [44].

In an effort to increase porcelain bonding, manufacturers of porcelains for Y-TZP ceramics provide liners or bonders. Liners may help to assure a perfect wetting of the framework surface. It may provide chemical adjustments to reduce possible interactions with Y-TZP. According to some manufacturers, wetting and bonding can only be provided by a wash-firing of the dentin porcelain mass. This consists of applying a thin wash of dentin porcelain, of 50mm thick and firing it at 50-80°C higher than the subsequent veneering porcelain [29].

Kappert and Eichner [44] asserted that zirconia-based restorations have chemical bonding similar to that of metal-based restorations. They claimed that Y-TZP, being a metal-oxide, develops a chemical bond with ceramic layer. They also noted that this is not proven for metal-ceramic and can be suggested for zirconia.

### 6.1 Is the Cause of the Reaction Occurring on Y-TZP Grains' Surface Well Determined?

Two types of Zirconia are available on the market: pre-sintered zirconia and HIP (hot isostatic pressing) zirconia [45]. It is well known that pure zirconium oxide exhibits three allotropes: monoclinic (m), which is the stable

phase up to 1170°C, where it transforms to tetragonal (t), and then cubic (c) at temperatures above 2370°C. The t-m transformation, which is martensitic, usually occurs during the sintering, on both heating and cooling. It is accompanied by a large shear strain and a volume increase [46]. This can create large internal stresses on cooling. This provokes inevitably the disintegration of pure zirconia sintered above 1170°C, by cracking upon cooling. To maintain the integrity of sintered zirconia bodies at room temperature, sintering at low temperature has been proposed. Zirconia remains monoclinic during sintering, but this leads to a low-strength and toughness ceramic. The tetragonal or the cubic phases at room temperature can also be stabilized by alloying, thereby avoiding the t-m transformation during cooling [47].

Properties and behavior of polycrystalline materials are strongly influenced by grain boundaries during processing and in service. When a significant fraction of the grain boundaries undergoes a transition in a polycrystalline material, the cumulative effect can be dramatic. Sudden change in macroscopic properties may occur [48]. According to Tholey [49], the veneering process affects the grains structure of the framework material, in some instances. He observed that the moisture has a clear role that leads to the faceting of grains at the Y-TZP interface. The intrinsic toughness of a material is referred to the inherent resistance to fracture, whereas extrinsic toughening is referred to mechanisms that act at crack tip. These mechanisms lower the local driving force experienced at the crack tip, e.g., via phase transformations or grain bridging [50]. Studies based on results in sapphire and silicate glasses, where extrinsic toughening is absent, showed that moisture leads to a reduction of the intrinsic resistance to crack advance, at sub-critical velocities [51]. This is consistent with moisture lowering of the relative toughness of the boundaries that was supposed to slow cracking [52].

The porosity of Y-TZP plays a role in destabilizing the tetragonal grains. Fully dense structures have a lower transformation tendency than the slightly porous materials with the same grain sizes [47].

Chevalier et al. [49] stated that the tetragonal to monoclinic transformation are induced by moisture. This phenomenon starts at grain corners, where the residual tensile stresses are largest. Water attack provokes a progressive

transformation of the grains. A grain does not transform all at once. The surface transformation of Y-TZP takes place by an apparent nucleation and growth mechanism. Nucleation is defined as the transformation of one grain, whereas growth is considered the extension to its near neighbors. Once the transformation is initiated at one grain, the extension of the transformation continues at the neighboring grains due to additional localized stress concentrations, in addition to the transformation that occurs at randomized sites [49].

In faceting of Y-TZP grains at the interface with porcelain, two distinct parts of the process are described.

- Incorporation of water in the veneering build-up procedure, during initial preparation. In the preheating phase of the moist veneering powder on Y-TZP, the temperatures quickly reach 100°C. The moist evaporates from the heated veneering powder and the underlying Y-TZP framework. When temperatures are between 100°C and 250°C, in a humid environment, the rate of transformation from tetragonal to monoclinic is quite rapid [49]. The formed monoclinic phase at the surface will resist in some localizations to temperatures that exceed 1000°C [33]. In the same grain, residual stresses will persist at the boundaries between monoclinic and tetragonal portions.
- At elevated temperatures, the layering porcelain liquefied. Some dissolution of zirconia grains in the feldspathic glass will take place at elevated temperatures. This reaction is increased at grain boundaries, in the tetragonal to monoclinic boundary interfaces where high stresses persist.

The presence of liquid in the veneering porcelain will initiate the tetragonal to monoclinic transformation. This stress will accelerate glass dissolution [47].

## **6.2 Do the Presence of Moisture that Induces Tetragonal to Monoclinic Transformation, Influence the Debonding of the Veneering Porcelain in Clinical Situation?**

The t-m transformation in zirconia is by definition martensitic. A martensitic transformation is a

“change in crystal structure . . . that is athermal, diffusionless and involves the simultaneous, cooperative movement of atoms over distances less than an atomic diameter, so as to result in a macroscopic change of shape of transformed regions” [53].

Y-TZP ceramics may suffer a slow t-m transformation at the sample surface in a humid atmosphere, followed by microcracking and a loss in strength [54]. The exact mechanism is still not well understood. The increase of internal stresses associated with a penetration of water species inside the lattice may trigger the initiation of transformation [55]. A cascade of events then follows. The transformation propagates first inside one grain, then invades the surface by a nucleation-and-growth (N-G) mechanism and the core for severe treatments [49].

In this sense, Low temperature degradation (LTD) is a competing process to transformation toughening. If the transformation is triggered by a propagating crack, then toughening can get enhanced. The process on a surface is complex. It results not only in the undesirable transformation but also induces surface roughening, microcracking, and grain pull-out as well as loss of strength. All these processes are detrimental to structural applications. The alloy designer faces this dilemma: The Y-TSZ alloys that have the most attractive fracture toughness, are also the most susceptible to LTD [46].

Phase transformation toughening originates from large tensile stresses around a crack. This can destabilize the tetragonal phase in the vicinity of the crack, and form a transformation zone [47].

It remains unknown to which extent these conditions are correlated. Some interfacial fracture toughness tests found that crack propagation occurred through the porcelain and not on the porcelain/Y-TZP interface [33]. Shear bond strength tests confirmed the occurrence of fracture within the porcelain [56]; whereas in the porcelain fused to metal (PFM) the cracking is observed directly at the interface between framework and porcelain [33].

Higher rate of complications have been reported for PFZ in comparison with PFM restorations [3,57]. This discrepancy in incidence rate remains not fully understood. Further studies on the zirconia surface preparation before porcelain layering are required. Sandblasting and grinding

have incidence on surface transformation. These stress-generating surface treatments may trigger the t-m transformation process. The surface compressive stresses will increase the flexural strength, but will decrease the resistance to the aging phenomenon [58].

## 7. FACTORS THAT MAY INFLUENCE BONDING STRENGTH

Aging occurs in zirconia samples, mostly in humid atmosphere or in water. Experiments show that water radicals do indeed penetrate inside the zirconia lattice when exposed to humidity. Most likely, the oxygen from the water is located on vacancy sites, and the hydrogen on an adjacent interstitial site. The presence of numerous vacancies due to the trivalent character of Y<sub>2</sub>O<sub>3</sub> in Y-TZP, makes the diffusion rate of species from the water higher than in other zirconia ceramics (i.e., CeO<sub>2</sub>-doped ZrO<sub>2</sub>). Martensitic transformation of grains (or part of grains) at the surface can then proceed [59].

Once a grain is transformed, the transformation is extended not only randomly on the surface, but also preferentially on the neighboring grains [48]. Nucleation occurs on the most unstable grains [with less Y<sub>2</sub>O<sub>3</sub> and/or with large size and/or subjected to higher internal stresses. This phenomenon happens when these grains are subjected to the highest tensile stresses (either internal or applied). The number of nuclei increases continuously with the stresses, in parallel with water penetration. At the same time, growth occurs because the transformation of one grain puts its neighbors under tensile stresses, favoring their transformation under the effect of water. The whole process is controlled by the diffusion of water species [49]. All the volume accessible by XRD shows a t-m transformation. However, a cross section by scanning electron microscopy (SEM) demonstrates that aging still continues into the volume of the material. The transformed layer appears rougher due to extensive pullout during polishing, with microcracks generated by aging [60]. Aging is really associated with roughening and microcracking [49].

It is now accepted that t-m Transformation in a grain is triggered by microscopic tensile stresses [59]. The same role can be played by macroscopical tensile stresses [58]. Thus, machining should be carefully controlled. Rough polishing generates compression stresses. This will delay aging, but the surface state induces

wear. Fine polishing provides an acceptable roughness, but this will remove the compressive stresses. Tensile stresses reappear along the residual scratches. Thus, fine polishing without any scratches is targeted [49].

Chipping can also be related to contact loadings. It is normally produced when a crack is generated or propagated by contact loads deflections [61,62]. Under tensile stress, brittle ceramic will fracture perpendicular to the applied force [63]. Several factors will increase the probability of crack propagation under loading, like as thermal coefficient mismatches, processing (porosity, impurity inclusion) and inherent material defects (large grains, residual scratches) [64]. Cracks will be triggered adjacent to these flaws [63].

A strong zirconia core–veneer bond is also required to gain profit from exceptional properties of the framework. However, Aboushelib noticed that this bond strength is lower than for other all-ceramic systems [15]. Chipping and delamination may be induced under friction. The bonding strength will be affected by the framework surface treatment, the surface finish, the type and method of application of the veneering ceramic [65].

If fractures of the zirconia framework are rarely reported [66], a rate of 20% for ceramic chip-off was observed at 5-years follow-up period [67,68]. Whereas in the case of metal framework FPDs, a review of the literature revealed substantially lower fracture rates ranging up to 5.5% for observation periods from 10 to 15 years [66,69, 70].

Proper framework design, adequate veneering ceramic support and thickness are factors implicated in the ceramic survival [35]. Furthermore, **occlusal forces**, including direction, magnitude and frequency have to be taken into consideration [71]. Chipping may be induced by roughness of the veneer due to occlusal contacts or grinding. Fractographic analysis revealed that crack propagation originated from occlusal adjustments and wear area [72,73]. Sharp indentations, even at very low loads, as well as sandblasting may be very harmful to long-term longevity of zirconia [74,75].

Scanning of full contour waxing will provide an optimal porcelain thickness on appropriate coping design [76]. The pontic framework must be designed in an **anatomical shape** to support

veneers' cusps. The veneer **thickness** should not exceed two-fold of the core thickness [77]. This will decrease porcelain fracture rate [78,79]. However, a completely suitable veneer system is still to be found. Differences in microtensile bond strength between several veneering porcelains remain [80]. Strong veneering systems are needed to avoid chipping [68].

Some authors argued that the **(CTE)** plays a main role far before the zirconia-veneer bond strength [72,81]. Manufacturers supply veneering porcelains that have a slight mismatch with that of zirconia, with the porcelain's CTEs lightly lower [80]. This will produce a desirable residual compressive stress in the veneering ceramic [82]. Whereas, when Zirconia's CTE is lower than ceramic's, veneer delamination and microcracks may occur [83]. This is recommended for most metal-ceramic systems and non-zirconia all-ceramic systems [34]. Therefore, the compatibility issue with Y-TZP is not likely due only to a simple thermal expansion coefficient mismatch between the bulk materials [34]. Low fusing veneering ceramics with similar CTE have been proposed. Grain size may also have an impact [28]. The wide range of sintering temperature will influence the particle size and so on the phase stability of zirconia-yttria [34].

A layering method of indirect composite onto a zirconia framework has been described by recent studies [15,82]. A short term in-vitro study reported a greater bond strength when using a priming agent containing the functional monomer MDP [40]. Using composite, especially in areas of high occlusal stress [15] may be advantageous for its plastic and viscoelastic effects, as well as susceptibility to creep and recovery [15,82].

The Zirconia's **thermo conductivity** is much lower than that of other framework materials [84]. This retards the ceramic cooling rate at the interface and generates thermal residual stress [85]. It may provoke thermal cycling delamination of the veneering porcelain [28]. The effect of different cooling rates (slow and rapid) on the bond strength between veneering porcelain and zirconia ceramics has been studied [86,87]. To reduce stress and veneer chipping, prolonged **cooling phases** have been proposed [77]. This slow cooling can ameliorate the resistance of the veneered zirconia restorations [73], and enhance the shear bond strength [87]. Yet, other studies found that adding 5min cooling in the furnace lowered the bond strength [86]. These conflicting

findings are the result of different testing and cooling methods [82].

To mask the opacity of the zirconia-core, it has been proposed to apply a **liner material**. Unfortunately, this increased the percentage of interfacial failure by reducing the core-veneer bond-strength [65]. Fischer confirmed the negative effect of liner application [81]. Aboushelib contraindicated their use in case of Press-on ceramics [80]. The lower strength of liners compared to dentine ceramic may be involved in these negative results. Still, others reported that liner materials enhances the bond strength between zirconia and some veneering ceramics [82].

## 8. WHAT FUTURE FOR ZIRCONIA AS A RESTORATIVE MATERIAL

The cost of zirconia frameworks remains higher compared to PFM restorations. Some costs are added by CAD/CAM equipments and personal trainings [88].

Case-reported multi-unit bridge restorations and implant fixed partial dentures initiate some confidence in zirconia as restorative material, with some full-mouth rehabilitations, despite limited scientific evidence [89]. Long-term in-vivo studies are needed to demonstrate survival in long span bridges. Even with their superior mechanical properties, porcelain chipping is reported to be related to zirconia frameworks. Porcelain mechanical properties remain almost framework independent.

To resolve this issue, manufacturers propose monolithic Y-TZP zirconia products. This new material is more translucent with better aesthetic properties than the conventional Y-TZP zirconia. When perfectly polished, studies claimed no abrasion impact on antagonist dentition [90,91].

Different zirconia materials are investigated with stabilizers others than yttria, like Ceria-stabilized zirconia alumina composites (Ce-TZP) [92], and magnesia partially stabilized zirconia (Mg-TZP) [93]. These new materials are more resistant to LTD and spontaneous phase transformation. They present higher fracture toughness but with a lower flexural strength compared to Y-TZP [92].

Y-TZP has the potential to be considered as a suitable material for fixed partial dentures. Randomized clinical trials with larger sample size

and longer *in vivo* observation periods are essential. However, chipping of the layering ceramic remains an issue. Zirconia is indicated for nearly all kind of restorations. Zirconia frameworks fracture is not an issue in the dental clinical cases. A simulation of 10-year clinical service study estimated framework fracture probability to be almost 0% [94]. However, in vivo trials of a period of less than 5-years have reported framework fractures [3,6,95]. Load to failure needed for Cercon zirconia 4-unit FPDs was of 379 to 501 MPa, much higher than the average human bite. This confirms the zirconia suitability to as FPDS substructure framework [96]. Chipping of veneering porcelain remains a non clarified problem. The major incidence occurred within 2 years after placement [5]. Delamination is not reported as an issue, but studies are needed, focusing on porcelain-zirconia interface.

The remarkable finding reported in the literature was the high frequency of cohesive failure of the veneering ceramic, with or without exposing the underlying zirconia framework. This problem was common to every Y-TZP brand [7]. In some cases, this occurred on non-load-bearing areas, with no set pattern identified so far [71,89]. This supported that the bond strength between Y-TZP and veneering porcelain was higher than the cohesive strength of the porcelain itself [92]. Consequently, the veneering porcelain is considered as the weakest link. Improving its strength was proposed to reduce veneering porcelain chipping incidence [97]. High-strength heat-pressed ceramics were considered [80]. Unfortunately, chipping problem persist with the use of pressed-ceramics [6,98].

Chipping fractures still occurred with the modified framework designs in a 3-years clinical trial [89]. The authors suggested that sandblasting prior to veneering process may have altered the zirconia crystalline structures. Complete delamination would have been expected instead of chipping, if that was the case.

The inherent spontaneous zirconia ageing problem in presence of water has lead to catastrophic failure of Y-TZP core [42]. This ageing phenomenon starts at surface grains and progresses towards the bulk material. It causes a flexural strength reduction of the material that might lead to the spontaneous catastrophic failure [99]. No catastrophic fractures have been reported in HIPed zirconia, but only on non-



HIPed zirconia [7]. This was an important finding, as hard-milling was pointed as product stress-generating.

## 9. CONCLUSION

Zirconia-based restorations emerge as a successful all-ceramic system with an acceptable longevity, with different clinical indications. Longer *in vivo* trials with larger samples are still needed.

It appears that veneering porcelain can wet and bond well to zirconia frameworks. However, chipping of the layering porcelain remains an issue to be resolved, more than delamination. PFM restorations have a higher success rate especially regarding debonding problem.

The moisture present in the veneering powder during porcelain layering onto Y-TZP structures can generate grain faceting at the surface of zirconia grains beneath the veneering ceramic. This phenomenon is also related to the firing temperature. Increased faceting are observed after high veneering porcelain firing temperatures, related to glass induced dissolution at sites of higher residual stresses at the tetragonal/monoclinic interfaces.

The presence of such transformed grains and their long-term consequence on the porcelain/Y-TZP interface need further investigations.

## CONSENT

It is not applicable.

## ETHICAL APPROVAL

It is not applicable.

## COMPETING INTERESTS

Author has declared that no competing interests exist.

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