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Review Article

Trends and perspectives in modification of zirconium oxide for a dental prosthetic applications – A review

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ABSTRACT

Full-ceramic dental restorations made from ZrO_2 have become increasingly popular due to their aesthetics and mechanical strength, and are gradually replacing prostheses made of porcelain fused to metal. Nevertheless, due to the variability in the physicochemical properties in a wet environment at elevated temperature, zirconia is quite a controversial material, the use of which in the environment of the mouth is questionable and raises many concerns. The reason for the variability in the physicochemical changes is the martensitic transformation in which metastable phases (β, γ) change into the stable phase (α). For biomedical applications, the most desired is the β-phase. A very unfavourable phenomenon accompanying the martensitic transformation in a wet environment is low temperature degradation, which is an autocatalytic process accelerating negative changes in ZrO_2. The aim of this review is a comprehensive study of the degradation phenomenon problems according to prosthetic treatment with a fixed prosthesis and ways to reduce it.

1. Introduction

1.1. *Materials used for dental prosthetic restorations and their limitations*

The observed progress in dentistry stems not only from the development of dental techniques and therapeutic procedures derived from many years of clinical experience. Introduction to the clinical practice of new medical techniques or new materials does not always finally achieve success, because this usually reflects the current state of knowledge and technical capabilities [1]. The process of integration of innovative technology and medicine is still unfinished. An avalanche of literature reports and the normative findings necessitates a periodic analysis and synthesis.

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List of abbreviation and symbols

ZLS	zirconia lithium silicate
FRC	fibre reinforced composite
FCR	fixed ceramic restorations
PFM	porcelain fused-to-metal
ZTA	zirconia toughened alumina
PSZ	partially stabilised zirconia
TZP	tetragonal zirconia polycrystals
YSZ	yttrium stabilised zirconia
CAD	computer aided design
CAM	computer aided manufacturing
TT	transformation toughening
FPD	fixed partial dentures
LTD	low thermal degradation
σ	tensile strength
FCR	fixed ceramic restorations
SCG	slow crack growth
K_{IC}	critical stress intensity factor
E_A	activation energy
MAJ	Mehl–Avrami–Johnosn model
MT	martensitic transformation

Prosthetic restorations can be divided into two broad types [2]:

- *Direct restorations* (involves placing a soft or malleable filling into the prepared tooth and building up the tooth before the material sets), and
- *Indirect restorations* (fabricated outside of the mouth using the dental impressions of the prepared tooth) include inlays and onlays, crowns, bridges, and veneers which are usually cemented using conventional methods of aesthetic dentistry.

The general aim of treatment is the implementation of such reconstruction, which in terms of colour, shape, anatomical and functional features would be the most similar to the lost tooth structure.

Particular issues in the engineering of drop-down materials constitute the quality characteristics of biomaterials and medical materials, determined on the basis of their functional applications. Also, their reactivity with the environment is subject to rigorous control both in the surroundings of the implanted biomaterial and the general reactivity of the organism [3].

First and foremost, dental biomaterial must be biocompatible – it should not elicit an adverse response from the body, should be nontoxic and noncarcinogenic when remaining in close contact with the surrounding soft tissues for an extended period of time. The subgingival placement is absolutely crucial as it has a direct effect upon the condition of marginal gingiva surrounding the teeth and implants. The most commonly used materials in prosthodontics are titanium, cast gold and chrome-cobalt alloy, as well as all-ceramic materials. The literature demonstrates that gold alloy and feldspathic ceramic had short-term cytotoxic effects and chrome-cobalt alloy had the highest cytotoxic effect on fibroblast cells [4]. Therefore, the next generation of high strength glass ceramics (ZLS) considered a level of extraordinary aesthetics (thanks to the excellent translucency, fluorescence and opalescence), outstanding strength and rapid processing, should be subjected to observation because of reports on the cytotoxicity of lithium disilicate, as demonstrated previously, suggesting that this component is not biologically inert, and that may have a similar cytotoxicity dynamic regardless of small differences in the composition or processing [5].

The *in vivo* strength degradation of restorations based on dental ceramics may occur in oral environments as a consequence of masticatory and parafunctional forces of more than 200 [3]. In the mastication process, besides the mechanical action of the dental arcades, an important part is played by saliva. Within the mouth, both the teeth and supporting gum tissues can be readily destroyed by bacterially controlled disease.

Also, dental casting alloys are widely used in prosthetic applications that place them in contact with oral tissues for many years. With the development of new dental alloys over the past 15 years, many questions remain about their biological safety – its corrosion. Systemic and local toxicity, allergy, and carcinogenicity all result from elements in the alloy being released into the mouth during corrosion. Several elements such as nickel and cobalt have relatively high potential to cause allergy, which is why dentists should select alloys that have the lowest release of elements (lowest corrosion) to minimise biologic risks. This goal can be achieved by using high-noble or noble alloys with single-phase microstructures [6–8] (Table 1).

Nowadays, in dentistry there are three groups of non-metallic materials used to manufacture prosthetic restorations:

- organic (different plastics);
- inorganic (ceramics);
- composites (organic + inorganic).

Acrylic resin materials that possess excellent aesthetic qualities are used to fabricate artificial teeth on removable partial dentures. However, porcelain teeth are more resistant to wear but more brittle than acrylic resin.

An innovative solution is a fixed prosthesis made from fibre-reinforced composite. They constitute an alternative to the restorations made of metal and ceramic or ceramic only. The design of a fixed denture fibre-reinforced substructure consists of an FRC, veneered with a molecular composite. The framework ensures durability, and is therefore veneered in a laboratory to ensure better aesthetics and improved physical properties compared with direct reconstruction of the composite [9].

Completely ceramic materials used for the fixed prostheses have a low elasticity and endurance, while composite materials showed less wear and had less colour stability. In this regard, newer composites have far superior properties [10]. For this purpose, new polymer structures are used, which are characterised by an increased dispersion of the filler particles. However, molecular composites are fragile and require a reinforced substructure that is resistant to bending. Although resin composite materials are weaker than metals,