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Review Article

Dental prostheses mimic the natural enamel behavior under functional loading: A review article

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Summary Alumina- and zirconia-based ceramic dental restorations are designed to repair functionality as well as esthetics of the failed teeth. However, these materials exhibited several performance deficiencies such as fracture, poor esthetic properties of ceramic cores (particularly zirconia cores), and difficulty in accomplishing a strong ceramic—resin-based cement bond. Therefore, improving the mechanical properties of these ceramic materials is of great interest in a wide range of disciplines. Consequently, spatial gradients in surface composition and structure can improve the mechanical integrity of ceramic dental restorations. Thus, this article reviews the current status of the functionally graded dental prostheses inspired by the dentino-enamel junction (DEJ) structures and the linear gradation in Young's modulus of the DEJ, as a new material design approach, to improve the performance compared to traditional dental prostheses. This is a remarkable example of nature's ability to engineer functionally graded dental prostheses. The current article opens a new avenue for recent researches aimed at the further development of new ceramic dental restorations for improving their clinical durability.

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1. Introduction

Teeth play a critically important role in our lives. Loss of function diminishes our capability to eat a stable diet, which has undesirable consequences for general health. Loss of esthetics can negatively influence social function. Both function and esthetics can be reconstructed with dental prostheses.

Material selection for dental prostheses has turned out to be a sizable field for researchers. Ceramics are frequently used in load-bearing biomedical applications due to their excellent biocompatibility, wear resistance and esthetics [1—3]. Ceramics are utilized as total hip and knee replacements [4—8] and adopted for dental restorations [9—11]. Ceramic dental restorations are designed to repair functionality as well as esthetics of the failed teeth. However these materials showed somewhat poor flexural strength, particularly when exposed to fatigue loading in wet environments [1—3]. Subsequently, it can cause extensively discomfort to patients and can reduce the durability for ceramic prostheses due to their flexural fracture [12—15].

The failures of dental restorative systems are due to incorrect selection of materials, incorrect design of the component, the incorrect processing of materials, and presence of defects (e.g. cracks and pores) in the prostheses [16—19]. Additionally, in metal—ceramic restorations there are mismatches in the mechanical properties between the veneering porcelain and metal core. The Young's modulus of the veneering porcelain is 60—80 GPa, while that of the metal core is in the range of 80—230 GPa [20]. Furthermore, there are mismatches in the thermal properties between the veneering porcelain and metal core, where coefficient thermal expansion for metal core is usually higher than veneering porcelain. The significant mismatch between both material properties concentrate stresses at the interfaces that may cause cracks at the metal—ceramic interface and consequently to the failure of the restoration [21,22]. Lastly, metal core is more susceptible to corrosion in which its effect ranges from degradation of appearance to loss of mechanical strength [23,24]. The corrosion products can produce a bluish-gray pigmentation of gingiva and oral mucosa. Furthermore, these products, particularly in immunologically susceptible individuals, can cause local and systemic hypersensitivities [25—28].

Despite a continuous improvement in the dental prostheses such as using a strong zirconia or alumina core to support the esthetic porcelain veneer, ceramic prostheses are still vulnerable to failure at a rate of approximately 1—3% each year [9]. Additionally, ceramics prostheses have a dense, high purity crystalline structure at the cementation surface that cannot be adhesively bonded to tooth dentin support [29,30]. Even though some authors recommended particle abrasion for surface roughening treatment to enhance the ceramic-resin-based cements bond using mechanical retention, particle abrasion also introduces surface flaws or microcracks that can cause deterioration in the long-term flexural strength of ceramic prostheses [31—37]. Further, zirconia cores have a white opaque appearance which needs a thick porcelain veneer with gradual change in translucency to mask the zirconia and to achieve a better esthetic outcome [38]. Further, the dental crowns generate over $2 billion in revenues each year, with 20% of crowns being all ceramic units. Also, aging populations will drive the demand for all types of dental restorations even higher [39]. Moreover, occlusal contact induces the deformation and cracking of dental crowns, which can lead to the failure of the structure [40]. Therefore, it is highly desirable to develop ceramic prostheses that are more resistant to cracking under occlusal contact in recent decade [17,18].

Composite ceramics have been designed in an effort to improve strength and toughness while expanding functionality. Simple laminate materials have been developed for many years, in which a number of materials with different properties are bonded into a layered structure [41]. Though these composites do combine varying properties, the abrupt interfaces between the two materials often hold residual stresses [42,43] and perhaps delaminate under load [44].

Recently, bioinspired functionally graded enamel structures in the design of dental multi-layers have been proposed, as alternative technique, aiming the enhancement of the overall performance of metal—ceramic and all-ceramic dental restorative systems. This technique allows the production of a material with very different characteristics within the same material at various interfaces. Bioinspired functionally graded approach is an innovative material technology, which has rapidly progressed both in terms of materials processing and computational modeling in recent years. Bioinspired functionally graded structure allows the integration of dissimilar materials without formation of severe internal stress and combines diverse properties into a single material system [45—47]. This innovative technology has been applied in medical and dental fields [48—56].

The graded structure eliminates the sharp interface resulting from traditional core-veneer fabrication, eliminating the potential for delamination between the layers [57]. Graded transitions can also reduce stress concentrations at the intersection between an interface and a free surface