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The mechanical behavior of the material-tissue and material-material interface in dental reconstructions ☆

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ABSTRACT

In dental and craniofacial sciences, frequently the goal is to replace lost or damaged natural tissue with synthetic materials. For ideal function, these replacement materials must strongly bond to the existing tissue, but they also must form a hermetic seal that eliminates the passage of microorganisms and fluids that would lead to further tissue destruction or weakening of the interface or the individual materials, compromising the final outcome. Therefore, the study of interfaces is crucial, and the manner in which they can be tested to predict the likelihood of success is of great interest to the field.

Because a variety of materials and material combinations are used for the repair or replacement of oral and craniofacial tissues, numerous types of material interfaces exist. A complete discussion of this important topic requires an examination of all of them. In this review article, the three different types of interfaces are treated separately. First, the interface between the tooth tissue and restorative material is explored, specifically by considering resin-based materials such as dental adhesives and composite, and the manner in which they interact with dentin and enamel. Second, the interaction between these same resin-based materials and other structures, such as oxide ceramic dental crowns, are explored, because these tooth replacement materials are typically fixed to the remaining tooth structure through the use of resin-based adhesives and cements, or repaired intraorally with similar materials. Finally, the interface between different synthetic materials, such as metals and ceramics, with dental porcelain used as an esthetic veneering material is addressed.

Contents

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1. The resin adhesive and tooth interface

1.1. Mechanical properties of enamel and dentin

Tooth structure is composed predominantly of hydroxyapatite, a calcium-phosphate crystalline mineral (Fig. 1). The enamel is almost totally mineralized, incorporating only a very small amount of organic matrix, being mainly protein (3 vol%), and water (12 vol%) [1]. The crystals are arranged in long rods having a very well defined radial anisotropy. Dentin is composed of approximately 47 vol% mineral, and containing 33 vol% of protein, mainly collagen with other non-collagenous proteins, and about 20 vol% water [1]. Dentin is arranged in a tubular structure, with a lower density of tubules near the dentin-enamel junction, and a greater tubular density, and subsequently lower mineral density, near the dental pulp. Therefore, the properties of dentin vary based on location within the tooth.

Enamel, typical of many ceramics, is a very brittle material, possessing high elastic modulus (~70–110 GPa) but relatively low tensile strength (10–70 MPa) and fracture toughness (0.7–2.1 MPa $m^{1/2}$) [2]. Dentin, in contrast, is of much lower elastic modulus (~20 GPa) than enamel, but has higher tensile strength (60–100 MPa) and is more fracture resistant (1.5–2.1 MPa $m^{1/2}$), all due to its higher organic content [2]. Enamel is also about 5–6 times harder than dentin. The most important aspect of the enamel-dentin complex is the interface, or transition region (Fig. 2), between the two, called the dentin-enamel junction (DEJ), which is estimated to be anywhere from 10–100 µm thick [3], though Gallagher et al. [4] used a combination of nano-indentation and Raman micro-spectroscopy to estimate the thickness as less than 10 µm.

There are many views as to how the DEJ provides enhanced toughening of the tooth, including the mismatch in elastic modulus between the dentin and enamel that arrests cracks [3] and crack bridging and localized microcracking within the enamel as the junction is approached [5]. The ultimate outcome is that there is significant energy dissipation at the interface, which often allows cracks to reach, but not extend into the dentin. In addition, there is strong adhesion between the enamel and dentin at the interface, with an apparent increase in fracture toughness as the DEJ is approached [3]. Thus, the DEJ provides a dramatic advantage over the individual tooth components that accounts for the fact that a very high proportion of teeth in humans have cracks, but they continue to function for many years, despite the fact that the outer enamel structure is compromised [6,7].

1.2. Mechanical properties of the adhesive interface

In modern dentistry, it is most typical to create bonded interfaces with enamel and dentin through resin-based adhesives and composites, both being composed of polymer matrices, and the latter especially being reinforced by inorganic particulates coupled to the polymer with a silane coupling molecule, thus securing that interface within the material. Resins are capable of flowing into micro- and macroscopic irregularities on the surface of the enamel or dentin and “locking” into the tooth structure once the resin becomes hardened. This adhesive force is predominantly a result of mechanical forces, but also derives from secondary bonding,

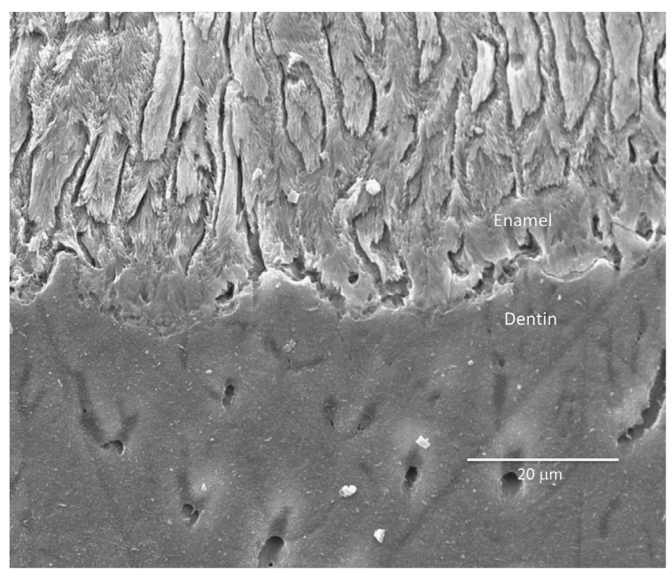

Fig. 2. Microstructure of the enamel-dentin junction.

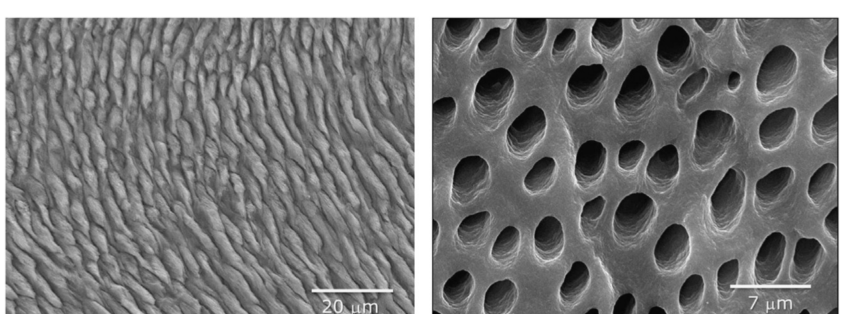

Fig. 1. Microstructure of enamel (left) and dentin (right) revealed by acid treatment showing the dense structure of enamel, which is composed of rods of hydroxyapatite mineral, and the porous structure of dentin, which is composed of hydroxyapatite mineral with protein surrounding the tubules.