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Crystal Orientation Correlates with Hardness in Enamels

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Teeth are subjected to extreme, repetitive forces on a daily basis. Human enamel withstands forces up to 770 Newtons, hundreds of times per day, and must remain functional for decades[1]. By comparison, great white shark enameloid withstands 7400 Newtons of force when biting, but teeth are shed regularly[2]. The mechanical stress the teeth undergo suggests that there are structural features in enamel that prevent catastrophic failure. Indeed, the composition and morphological structure of enamel make it wear resistant[3]. It is known that hardness is a property that linked to the elastic modulus as well as various measures of wear resistance, so it is a good property to assess mechanical performance of biological materials[4]. As in other biominerals[5], enamel crystals are space-filling, but crystal mis-orientation has not been correlated with mechanical performance.

Question: Is there a relationship between the degree of crystal misorientation in the tooth enamel of diverse animals and the hardness or mechanical parameters?

Methods: We used PIC (polarization-dependent imaging contrast)[6,7] mapping at the calcium L-edge[8] with minimal radiation damage[9] to reveal the crystal orientations within mammalian enamel rods and fish enameloid bundles. We used a nanoindenter to acquire multiload indents on the same samples that were PIC mapped in order to measure the hardness and elastic modulus. We corrected for structural compliance arising from various edge conditions following the procedure laid out in Jakes *et. al.* 2009[10].

Results: Analysis of PIC maps of enamel from different mammals including mouse[8] and human[12] and enameloid from different fish such as parrotfish[13] and a variety of different sharks indicates that c-axis orientations of adjacent crystals are slightly misoriented by a few degrees, the mean misorientation ranging from 2.2°-5.7°. The observed misorientation is positively correlated with the hardness and elastic modulus.

Conclusions: Apatite crystal misorientation correlates with hardness and elastic modulus and may cause enamel to be wear resistant.

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