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Hardness and yield strength of dentin from simulated nano-indentation tests

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Summary The finite element method (FEM) is applied for studying the hardness (*H*) and yield strength (*Y*) of dentin subjected to a nano-indentation process. The nano-indentation experiments were simulated with the ABAQUS finite element software package. This test, performed with a spherical indenter, was simulated by axisymmetric finite element analysis. The load versus displacement was calculated during loading—unloading sequence for different elastic modulus (*E*) and yield strength. Hardness and maximum principal compressive and tensile stresses were plotted for different elastic modulus depending on yield strength. The dentin was assumed to be isotropic, homogenous and elasto-plastic. The theoretical results outlined in this study were compared with the experimental works reported in the literature and then hardness and yield strength of dentin was estimated.

1. Introduction

Physical properties are important in the characterization and ranking of tooth. Cutting a tooth to testing dimensions for conventional tests is difficult, especially when the specimen is prepared to evaluate enamel, dentin or cementum separately. Hardness tests by indentation have the advantage of being simple, cheap, reproducible, and relatively non-destructive. Indentation test results revealed mechanical properties that are more directly related to the local structure of the tooth.

Nano-indentation has become a common technique for the determination of local mechanical properties of structural features in biological hard tissues [1,2]. Although nano-indentations only examine a thin surface layer, the mechanical properties obtained are assumed to be representative of the bulk material (i.e., dentin). Indentation has been utilized previously for the examination of dental tissue. With the advent of indentation instruments with continuous depth sensing capability, detailed studies on hardness, as well as elastic modulus became possible [3—5]. Fong et al. [6] investigated nano-hardness and elastic modulus of human incisor teeth across the dentin—enamel junction. They found that by increasing the contact area across the interface between two hard tissues

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Table 1 Material properties of dentin used finite element simulation

	Elastic modulus, *E* (GPa)	Yield strength, *Y* (MPa)	Poisson's ratio, ν
Sample 1	18.0	50—75—100	0.31
Sample 2	21.5	50—75—100	0.31
Sample 3	25.0	50—75—100	0.31

the stresses were dissipated, reducing interfacial stress concentrations at the dentin—enamel, thereby promoting effective load transfer from the hard (brittle) enamel to soft (tough) dentin. Similarly, Van Meerbeek et al. [7] used nano-indentation to characterize the hardness and elasticity of the resin—dentin bonding area. Also Cuy et al. [8] worked to map out the properties of dental enamel over the axial cross-section of a maxillary second molar using the nano-indentation test.

The aim of this study was to estimate the yield strength by simulating a load—displacement experiment using modulus data for dentin

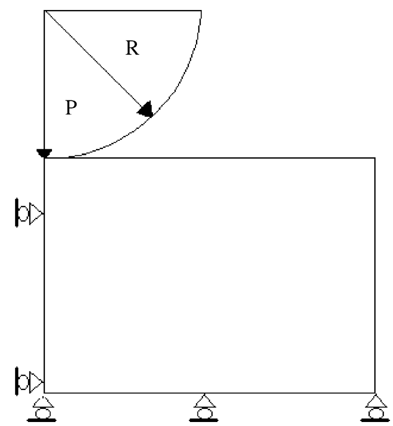

Fig. 1 Schematic representation of the nano-indentation model showing the materials and boundary condition.

2. Computational methods

The finite element was used for the nano-indentation test under the loading and unloading condition. This test with a spherical indenter was modeled as a contact problem between two axisymmetric bodies. In this study, three different samples of dentin were used as seen in Table 1. The specimen was modeled with 4950 4-node axisymmetric elements. The indenter was modeled as an undeformable surface and the radius of indenter (*R*) was 10 μm as seen in Fig. 1. The simulations were performed using ABAQUS finite element code.[1] The indentation region was small-modeled using edge-biased type. The contact constraint was enforced by the definition of the 'master' and 'slave' surface. We have chosen indenter surface as the master deformable surface due to the greater stiffness of the indenter with respect to the specimen. A resultant load of 10 mN was applied as the surface pressure of the indenter. Increasing load from zero to the value of 10 mN and decreasing load from 10 mN to the zero simulated the indentation test. At each load increment, the program caries out a large number of iterations according to a specified convergence rate to reach an equilibrate and congruent configuration.

A typical load versus displacement curve resulting from such an experiment may be seen in Fig. 2. The indenter establishes the contact with the material at A and the load increases along AB, the loading curve, as the indenter penetrates the material. BC is the unloading curve. If the material is perfectly elastic and has no hysterisis, then AB and BC will be identical. AC gives a measure of permanent deformation, if the material is not elastic. The area ABB′ gives the total work done on the material, the area CBB′ represents the amount of energy that has been recovered elastically and the area ABC gives the energy that has been used to create the permanent impression. For a perfectly plastic material, there is very little elastic recovery hence area BB′C → 0, while for a perfectly elastic material area ABC → 0.

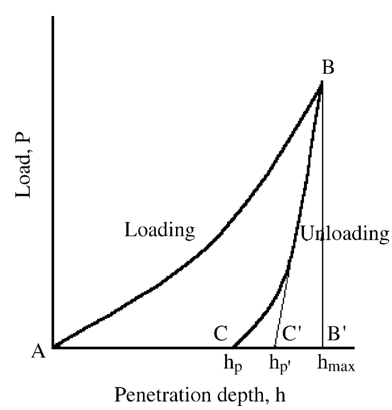

Fig. 2 Typical load—displacement curve of the nano-indentation test.

[1] Hibbitt, Karlsson and Sorenson, USA.