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# Numerical modeling of resin flow through a demineralized dentin collagen network

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## ABSTRACT

To restore a tooth, practitioners need to make the most reliable bonding of a resin to the biological support. Enamel material is now well known in dentistry and conditions of optimal bonding to it are standard practice. However, adhesion to dentin is still dependent on an understanding of the properties of the substrate which represents a healthcare critical issue. Two porosity scales are infiltrated: therapeutic porosity made of collagen fibers (nanoscale) and a natural one made of tubules scattered among the dentin (microscale). The quality of this bond depends strongly on the deep infiltration of a resin through the collagen fibers that creates a micromechanical seal responsible for bond efficiency and durability. The topology of these fibers is however so complex and unstable that the estimation of the permeability and consequently resin penetration depth is not possible using classical simplified approaches or permeability experiments.

Accordingly the purpose of this presentation is to present a model of the tissue at the nanoscale of the fibrous network based on a statistical distribution of the viscosities both of the collagen network and the fluid. Indeed the network of collagen fibers is statistically distributed according to Scanning Electron Microscopy images and Mercury Intrusion Porosimetry results and the process to build the network is based on a new technique materializing the fibers implicitely using a regularized Heaviside function. When macroscopic pressure boundary conditions and assumed Stokes flow are applied to a representative volume a numerical estimation of the demineralised dentin collagen network permeability K is obtained from the mean value of the flow velocity and the pressure gradient:

$$\langle v \rangle = K \langle \nabla p \rangle$$

To take into account the infiltration of the resin in the porous dentin and thus to estimate the parameters that are influencing the resin penetration depth into the porous network, an advancing saturation front is described using the level set method. Two correlated problems have to be defined: a Stokes problem for the fluids flow and the level set equation for the evolving fluid interfaces.

The fluid flow is governed by the Stokes equations written for the three fluids, the third fluid corresponds to the fibers with a very high viscosity in our approach. The Stokes equation is augmented by a capillary pressure Dirac delta function of the interface oriented along the unit normal n and proportional to the local curvature K of the front:

$$\rho \frac{\partial u}{\partial t} = -\nabla p + Div(\mu \epsilon(u)) + \sigma K n \delta_S$$

The level set function, $\phi$ whose remarkable property is to vanish along the interface is assumed to be transported by the flow u and satisfies thus the following advection equation:

$$\frac{\partial \phi}{\partial t} + (u, \nabla \phi) = 0$$

The three dimensional finite element coupled approach that will be illustrated here allows to estimate the penetration of the resin and thus the contact area between the final dry material and the dentin on which the strength of the bonding depends critically.