A MICROMECHANICAL MODEL OF THE PERIODONTAL LIGAMENT

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INTRODUCTION

A micromechanical model of the periodontal ligament (PDL), a thin layer existing between a root of a tooth and the alveolar bone is considered. The PDL is considered as a nanocomposite material comprising corrugated collagen fibrils and viscous gel-like ground substance. The individual cell of the composite material, with the effective properties reflecting the properties of the fibrils and ground substance, is considered.

MECHANICAL MODELLING

It is supposed in the model that the collagen fibrils and the ground substance form a two-layer coaxial cylinder with curvilinear axis. The diameter of the external cylinder is chosen according to the volume fraction of the collagen fibrils. The general equations for the bending/tension strain states of this composite beam are written in the frame of geometrically nonlinear Reissner's beams, supposing that (i) the constituent materials (fibril and matrix) are linearly elastic and isotropic; (ii) there is no mechanical interaction among the fibrils; (iii) each subunit bears the normal and bending loading; (iv) the absence of shear strains; (v) the absence of distributed loads and moments. By assuming a small undulation of the fibrils axis it is possible to get an approximate analytical solution of the governing equations, from which stress-displacement curves can be obtained, showing the dependence of the apparent strain on the external stress, and, thus, the dependence of the PDL elastic modulus on the load level. To model at least the initial locking effect in the PDL under compressive loading we change the Young modulus of the ground substance to its bulk modulus.

RESULTS

Some results are presented for the following values of the mean parameters of the PDL: wavelength of the undulation λ=10, 16, 24 μm, maximal angular deflection of the fibril from the straight axis, θ_0 =15^o, 20^o, 25^o, average radius of the fibril cross section $r_f = 150\,nm$, Young's modulus of the collagen fibrils E_f = 40 MPa, Young's modulus of the ground substance $E_m = 2\ MPa$, fibrils' volume fraction $f = 0.3\text{-}0.7$.

The dependency of the normal stress in a single fibril on the apparent strain is given in Figure 1. The variation of the maximal undulation angle has a strong influence on the stress-strain distributions. A similar dependency, accounting for the ground substance influence, is given in Figure.2. For strains larger than 6%-7% we can consider the PDL layer as a solid shell with Young's modulus approximately equal to the modulus of the fibrils. The value of the Young modulus at zero strain is the effective modulus of the wavy fibrils.

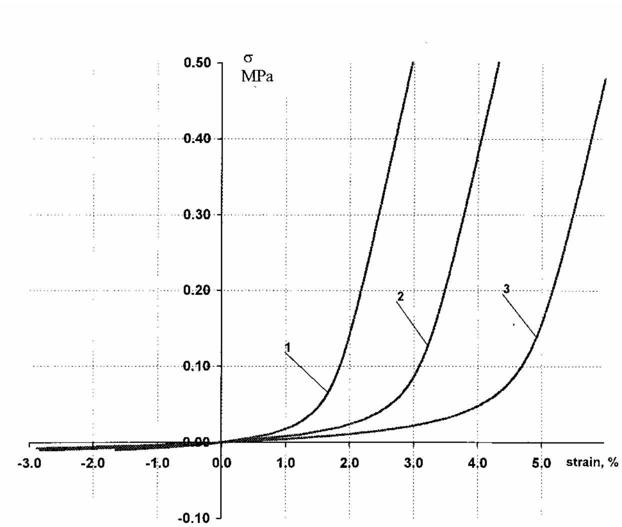

Figure 1: External stress vs. apparent strain in a single fibril: wavelength λ=16 μm, E_f=40 MPa, r_f=150 nm , lines 1, 2 and 3 correspond to θ_0=15^0 , 20^0 and 25^0 .

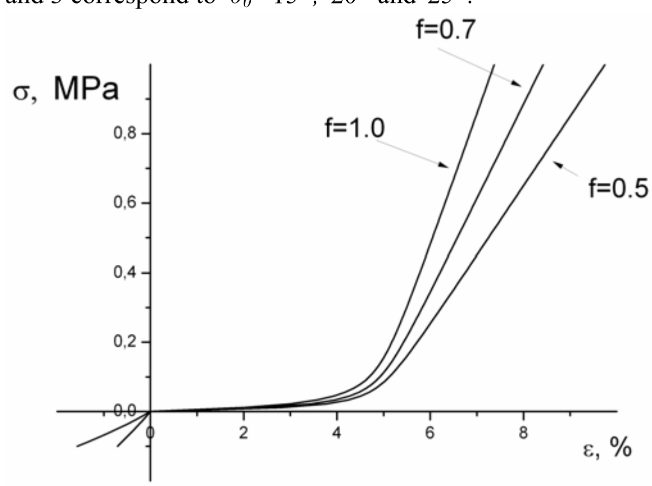

Figure 2: External stress vs. apparent strain, λ=16 μm, θ_0 =25^o, r_f= 150 nm , f = 0.5 and 0.7 including compression, f = 1.0 without ground substance.

CONCLUSION

The proposed micromechanical model is based on a physical-mechanical ground, and its material parameters are physical quantities that can be experimentally determined; it offers a direct way to determine the influence of the problem parameters on the stress state of the tooth-PDL-bone system.

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