A Nonlinear Model to Simulate the Viscoelastic Behavior of Periodontal Ligament

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Introduction

The function and the role of periodontal ligament (PDL) are of interest in many areas of dentistry. Due to the impossibility of specimen obtainment, the properties of PDL are still uncertain. It is generally accepted that the functional role of PDL is primarily tooth support. However, theories of how the PDL provides tooth support vary from the classical hammock theory to the viscoelastic theory. The prevalent tooth support theories have to consider a multiphase system comprising all components of PDL. In this paper, we will develop four models to discuss the property of PDL, and determine which material model is most suitable to represent the PDL behavior.

Methods

In this research, a maxillary central incisor was embedded and sectioned into 19 slices for construction of a three dimensional finite element model. The material of PDL was assumed to be viscoelastic, and the creep behavior was caused by two means—free fluid/vascular system and distortion of PDL itself. We proposed two linear viscoelastic models, volumetric and deviatoric, to study the differences between fluid flow and material distortion respectively. To include the nonlinear effect, the finite strain viscoelastic model was proposed. The material constants of creep behavior were obtained by retrograde calculation of Ross’s creep experiments (Ross et al., 1976) and Parfitt’s nonlinear tooth movement experiments (Parfitt, 1960).

Results & Discussion

The finite strain viscoelastic model is capable of describing both time nonlinearity and geometric nonlinearity. First, for the creep curve fitting, all the models including viscoelasticity can represent the curve well, except the unloading period (Fig. 1). The linear isotropic viscoelastic model is capable of describing the creep behavior of teeth. However, it does not describe the nonlinear load-displacement of the PDL material completely. Second, to simulate the nonlinear stress-strain behavior of tooth displacement, we use finite strain viscoelastic model, and found that it can simulate the curve adequately (Fig. 2). Finally, to find out the dominant source of creep, we compare the pressure stress change in creep test in our models with the results of Walker (Walker et al., 1978), and found that the volumetric viscoelastic model can be used to model pressure stress change in PDL and the dominant sources of creep are the free fluid and vascular system (Fig. 3). In brief, the finite-strain viscoelastic model can demonstrate both the creep effects and the nonlinear stress-strain relation of PDL. Further research is still required to discuss the material constants.
References

Fig. 1 The curve fitting of creep test data of Ross’s experiment.

Fig. 2 The typical nonlinear curve fitting

Fig. 3 The pressure in PDL in finite-strain viscoelastic model