RESIDUAL STRESS ASSESSMENT IN HUMAN FACIAL TISSUE DUE TO ISOTROPIC GRADUAL GROWTH

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Introduction

Growth and remodeling are among the main features of living tissues. Within the growth mechanics, living systems can be formulated by mechanical phenomena and continuum mechanics. As shown by Fung's experiments, biological tissues are not stress-free even when entirely unloaded. Moreover ignoring the residual stress and its effects may lead to erroneous results [1]. The exact origin of residual stresses in living tissues is not clear, but one of their main causes is tissue growth.

In this research, we have implemented the concept of fictitious configuration for growth mechanics in order to determine the residual stresses due to growth in the tissues. Tissue growth itself occurs in response of the changes in the stress state, but at the same time growth under loading changes the equilibrium state of stress. Hence determining the residual stresses due to growth requires an iterative method. We propose a gradual growth method together with a loading-growth-unloading procedure to estimate tissues residual stresses. The method is applied to a model of healthy human facial tissues.

Method

Let F shows the deformation gradient tensor. Using multiplicative decomposition, we introduce the elastic (F_e) and growth (F_g) part of deformation as:

$$F = F_e F_g \qquad (1)$$

To model the behaviour of soft tissues, we use a 5-parameter Mooney-Rivlin function (see Table 1) as the energy strain potential with an incompressible constraint, which represents a nonlinear isotropic hyperelastic material. Since only the elastic tensor F_e generates stress, we use this tensor instead of the total deformation gradient *F* in the expression of strain energy potential [2].

C_1	C_2	C_3	C_4	C_5
2.5E+3	0	1.175E+3	0	0

Table 1: Mooney-Rivlin Material Constants Used in This Paper

We use the isotropic growth law, which is one of the most widely used models in the literature. We thus parameterize the growth tensor, F_g, as a multiple of a growth multiplier θ_g by second order identity tensor I,

$$F_g = \theta_g I \qquad (3).$$

To determine the residual stresses due to growth, we propose a gradual growth method together with a loading-growth-unloading protocol. Based on this, we first simulated the behaviour of solve the finite element model under external mechanical loading and boundary conditions. Then, under loading condition, growth is applied by using the growth multiplier θ_g. In each step, this growth multiplier is increased to a maximum value with a specified velocity. Finally, in the unloading step, the external loads on the grown model are removed. The remained stresses are thus supposed to represent the residual stresses due to growth.

Results

The loading-growth-unloading sequence was evaluated on a finite element model of face [3] with a loading representing gravity. After this loading step, growth was applied gradually to the maximum value of θ_g=2 (Fig. 1) which seems reasonable according to the literature [4]. After removing the effect of gravity, the residual stresses due to growth in the facial tissue is then computed (Fig. 2 and Table2).

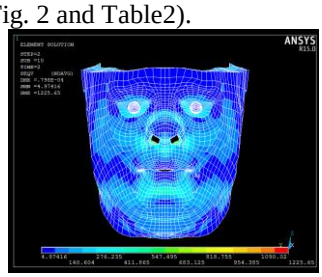

Figure 1: Von-Mises stress distribution in grown mechanically loaded configuration

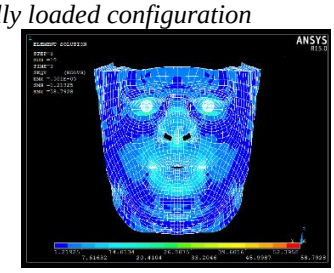

Figure 2: Von-Mises stress distribution in grown mechanically unloaded configuration (residual stress)

From Fig.1 to Fig.2, the stress field has been made more uniform and homogenous as a consequence of growth.

	Comp. stress	Tens. stress
Loading	3.17	963.56
growth	4.97	1225.65
Unloading(res. Stress)	1.21	58.79

Table 2: max and min value of stress in each step (pa)

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