Triaxial Contractile Mechanics of Arteries

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ABSTRACT

Few multiaxial constitutive laws under the vasoactive condition have been proposed as compared with those under the passive condition. The author and his colleagues have studied biaxial isometric properties of vasoactive rabbit arteries [1] although the constitutive law has not been proposed.

The experiments for 10 common carotid arteries of rabbit were performed under the passive condition and the constricted smooth muscle condition with the activation of noradrenaline (NA) 10^{-5} M [1]. This NA concentration provided the saturated smooth muscle constriction of arteries. The axial stretch ratio was set 1.5 and the intraluminal pressure was continuously increased and decreased between 0 and 200 mmHg. The intraluminal pressure, outer diameter, and axial force were monitored and recorded by a personal computer after A/D conversion.

For the passive mechanical properties, a strain energy density function proposed by Holzapfel et al. [2] was adopted:

$$W_{passive} = \frac{\mu}{2}(I_1 - 3) + \frac{k_1}{k_2}(\exp\{k_2[(1-\rho)(I_1-3)^2 + \rho(I_4-1)^2]\} - 1) \qquad (1)$$

$$I_1 = \lambda_\theta^2 + \lambda_z^2 + \lambda_r^2, \quad I_4 = \lambda_\theta^2 \cos^2\varphi + \lambda_z^2 \sin^2\varphi$$

where μ and k_1 represent constants with the dimension of energy density (kPa), λ_k $(k = \theta, z, r)$ denote stretch ratios in each direction, k_2 and $\rho \in [0, 1]$ nondimensional constants, and φ is a mean fiber angle against the circumferential direction, respectively.

The purpose of the present study is to describe the three-dimensional active mechanical properties of arteries. A novel strain energy density function for the active stress has been proposed:

$$W_{active} = C \tanh(a_\theta \lambda_\theta + a_z \lambda_z + a_r \lambda_r - a) \qquad (2)$$

where C represents a parameter with the dimension of energy density and depends on NA concentration, and a_k, a are nondimensional positive constants, respectively. Because the arterial wall is incompressible, $\lambda_\theta \lambda_z \lambda_r = 1$. This strain energy density function is simple and may describe the multiaxial characteristics of constricted large blood vessels. Although this study used mean stresses and mean stretch ratios to determine the mechanical properties of the vessels, a three-dimensional constitutive law of the constricted vessels has been developed. The strain energy density under the constricted condition is the sum of $W_{passive}$ and W_{active}. The material constants of the strain energy density functions were determined by the nonlinear regression using MATLAB with Optimization Toolbox. Each material parameter was represented as follows (mean±standard error): μ =25.68±5.82 (kPa), k_1 =2.61±1.27 (kPa), k_2 =2.12±0.32, ρ =0.898±0.051, φ =33.2±3.3 (deg); C =56.39±13.64 (kPa), a_θ =2.87±0.56, a_z =1.07±0.22, a_r =1.30±0.51, a =5.70±1.20.

REFERENCES

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