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Letter to the Editor

Evaluation of nonlinear elastic behaviors of skin

John Z. Wu and Robert G. Cutlip
National Institute for Occupational Safety & Health, Morgantown, WV 26505, USA

HENDRIKS ET AL. (1) have recently published a paper investigating the elastic properties of human skin *in vivo* via the optical coherence tomography. In their studies, the elastic properties of skins in forearms of 13 subjects have been determined. Hendriks et al. fitted the elastic behaviors of the skin using a Mooney model, which is governed by a strain energy density function:

$$W = C_{10}(I_1 - 3) + C_{11}(I_1 - 3)(I_2 - 3) \qquad (1)$$

Assuming small deformation and incompressible material properties, Hendriks et al. (1) obtained an initial elastic modulus, $E = 6C_{10}$. They found that the elastic modulus of their samples was around 0.069 MPa, which is much smaller than those reported by Barel et al. (2) (0.13–0.26 MPa). They attributed this huge difference to omitting the effects of C_{11}, and suggested that these parameters were not directly comparable. Although we agree with Hendriks et al. (1) that the elastic material behavior can be more appropriately simulated using a nonlinear model than using a linearly elastic model, we feel it is not an appropriate approach to evaluate the elastic stiffness of skin by comparing the material parameters of different models. We believe that the elastic deformation behaviors of the skin defined using different models should be compared by evaluating their stress/strain relationships, rather than merely comparing the material parameters.

For incompressible material in uniaxial stretch, the stretch ratio in the loading direction is $\lambda_1 = \lambda$, $\lambda_2 = \lambda_3 = \lambda^{-1/2}$, and the corresponding nominal strain is $\varepsilon = \lambda - 1$. The first and second invariant of the strain tensors are obtained as $I_1 = \lambda^2 + 2\lambda^{-1}$ and $I_2 = \lambda^{-2} + 2\lambda$, respectively. The nominal stress in the stretch direction can be obtained by differentiation of the strain energy density function (Eq. 1):

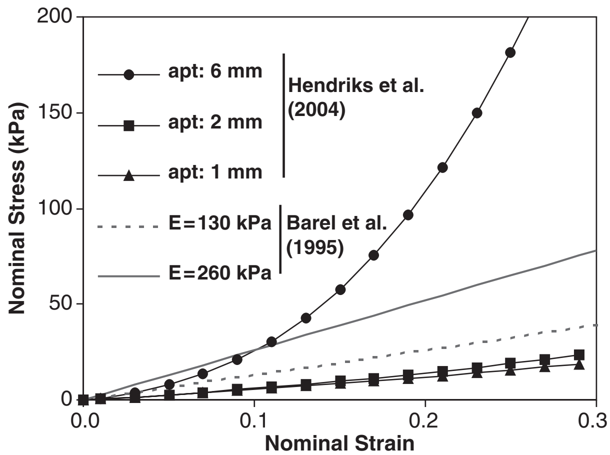

Fig. 1. Comparison of the stress/strain relationships by Hendriks et al. (1) with those reported by Barel et al. (2). The material parameters used in the graphs are (1) C_{10} = 663 MPa and C_{11} = 127 MPa for 1 mm aperture diameter, C_{10} = 652 MPa and C_{11} = 144 MPa for 2 mm aperture diameter, and C_{10} = 158 MPa and C_{11} = 216 MPa for 6 mm aperture diameter.

$$\begin{aligned}\sigma(\lambda) = \frac{dW}{d\lambda} &= 2C_{10}(\lambda - \lambda^{-2}) \\ &+ 2C_{11}[(\lambda - \lambda^{-2})(\lambda^{-2} + 2\lambda - 3) \\ &+ (\lambda^2 + 2\lambda^{-1} - 3)(-\lambda^{-3} + 1)] \qquad (2)\end{aligned}$$

Using Hendriks et al.'s material parameters for 1, 2, and 6 mm apertures, we derived the stress/strain relationships and compared them with those obtained using Barel et al.'s data, as in Fig. 1. We found that the elastic deformation behaviors of skin obtained by Hendriks et al. (1) are reasonably consistent with those reported by Barel et al. (2) for a strain range up to 0.15.

References

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Address:
John Z. Wu
NIOSH/CDC
1095 Willowdale Road, MS-2027
Morgantown, WV 26505
USA

Tel: +1 304 285-5832
Fax: +1 304 285-6265
e-mail: jwu@cdc.gov