Biomedical Engineering: Recent Developments. J Vossoughi (Editor), ISBN: 1-930636-01-6

CHARACTERIZATION OF NONLINEAR AND TIME-DEPENDENT BEHAVIOR OF SKIN UNDER COMPRESSION

John Z Wu, Ren G Dong, W Paul Smutz
National Institute for Occupational Safety and Health, Morgantown, West Virginia, USA

ABSTRACT
The vibration energy dissipation in the hand and fingers, which has been associated with vibration-induced injuries, is directly related to the biomechanics of skin and subcutaneous tissues [1]. Therefore, biomechanical properties of skin and subcutaneous tissues are important for the understanding of the pathomechanics of work-related neural and vascular diseases. The soft tissues in fingers are mostly in compression under physiological loading conditions. However, the published mechanical properties of skin [e.g., 2-3] were obtained exclusively during tensile loading. The goal of the present study is to develop a methodology to characterize nonlinear and time-dependent behaviors of skin in compression. Pigskins were used in the present study. Three series of tests were performed: (a) stress relaxation, (b) slow confined compression (1 μm/s), and (c) slow and fast unconfined compressions (1 and 100 μm/s). The parameters in the constitutive model were identified using the force relaxation, slow confined and unconfined compression tests (1 μm/s), while the fast unconfined compression test (100 μm/s) was used to validate the constitutive model. A nonlinear finite element model (FEM) was developed for the model parameter identification and model validation. Our results suggest that the mechanical behaviors of skin tissues are highly nonlinear and time-dependent; and the deformation behaviors of these soft tissues can be satisfactorily described using the Ogden form.

MATERIALS AND METHODS

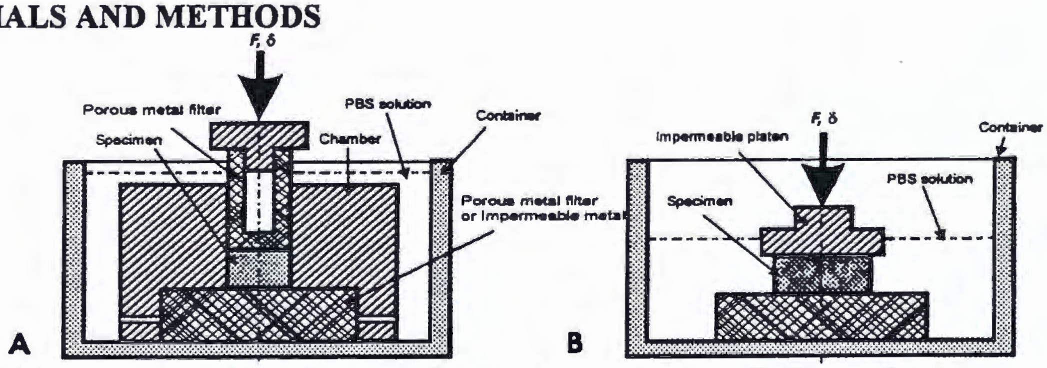

FIGURE 1. Experimental set-up. A. Confined compression; B. Unconfined compression.

Pigskins from upper front legs were used in the study. All specimens were cylindrical and had the same diameter (6.35 mm). The height of the specimens for the confined and unconfined compressions was 2.25 and 1.64 mm, respectively. In the confined compression, the lateral displacement of the specimen was restricted (Fig. 1A); while in the unconfined compression, the lateral surface was free to expand (Fig. 1B). Throughout the tests, the specimens were submerged in phosphate-buffered saline (PBS) bath (pH 7.4) at room temperature (22°C). The tests were performed at a displacement-controlled protocol using a universal micro-mechanical testing machine (Type: Mach-I, Biosyntech, Montreal, Canada). The skin specimens were pre-conditioned by cycling several times at a magnitude of 20% of the testing strain before the data collection. The stress relaxation tests were performed under unconfined compression (Fig. 1B). The specimen was compressed, at a fast speed (1 mm/s), to a nominal strain of approximately 10%; the compression was then kept constant, while the loading as a function of time was measured. In the confined compressions, the specimens were compressed at a speed of 1 μm/s (corresponding to a strain rate of 0.0004 1/s); while in the unconfined compressions the specimens were compressed at 1 and 100 μm/s (corresponding to strain rates of 0.0006 and 0.06 1/s, respectively). At a slow loading speed of 1 μm/s, the force/deformation is considered to represent the long-term characteristics of the skin tissues. In order to identify the parameters in the constitutive model, axi-symmetric FEM models were developed using ABAQUS (HKS, Version 6.2). The skin was assumed to be nonlinear, almost incompressible, and viscoelastic. The long-term deformation behaviors and the time-dependent characteristics were described using a three-term Ogden form and a three-term Prony series [4], respectively.

RESULTS AND DISCUSSION

The stress relaxation (Fig. 2A), confined and unconfined compression tests at slow rate (1 μm/s) (Figs. 2B and 2C, respectively) were used to identify the model parameters, while the unconfined compression at fast rate (100 μm/s) (Fig. 2C) was used to validate the model. The present results showed that the skin tissues are highly nonlinear and time-dependent in compression. The good agreement between the model predictions and experimental data suggests that the mechanical behavior of the skin in compression can be well described using the Ogden form combined with a Prony series. Our results show that the stress/strain curve is much stiffer in confined compression compared to that in unconfined compression, indicating that the skin material is almost incompressible.

In the present study, we proposed to use both confined and unconfined compression together with FEM to characterize the nonlinear and time-dependent behaviors of skin. Pigskin was used in our study; however, it is presumed that the proposed methodology can be applied to any skin and subcutaneous tissues.

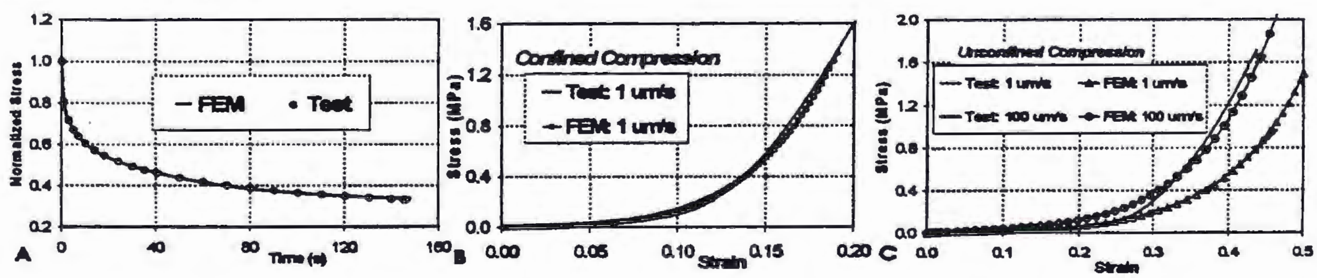

FIGURE 2. Comparison of the model predictions (FEM) with the experimental measurements. A. Stress relaxation test; B. Confined compression; C. Unconfined compression.

REFERENCES

1. Burstrom, L, The influence of biodynamic factors on the absorption of vibration energy in the human hand and arm. Nagoya J Med Sci, 1994. 57(3-4):159-67.
2. Wilhelmi, B, Blackwell S, Mancoll J, Phillips L, Creep vs. stretch: a review of the viscoelastic properties of skin. Ann Plast Surg, 1998. 41(2):215-9.
3. Wan, AW, Biaxial tension test of human skin in vivo. Biomed Mater Eng, 1994. 4(7):473-86.
4. Tschoegl, NW, The phenomenological theory of linear viscoelastic behavior: An introduction. 1989: Springer-Verlag, New York.

BIOMEDICAL ENGINEERING RECENT DEVELOPMENTS

JAFAR VOSSOUGHI, Editor

MEDICAL and ENGINEERING PUBLISHERS, Inc, *PO Box 11834, Washington, DC 20008*

BIOMEDICAL ENGINEERING RECENT DEVELOPMENTS

Proceedings of the
Twenty First Southern Biomedical Engineering Conference
September 28 – 29, 2002
Bethesda Hyatt Regency
Bethesda, Maryland, USA

JAFAR VOSSOUGHI
Editor

Biomed Research Foundation
3616 Martins Dairy Circle
OLNEY, MD 20832
Tel/Fax 301 570 9771
E-mail: Vossoughi@transinfo.com