ESTIMATION OF VISCOUS PROPERTIES OF SKIN AND SUBCUTANEOUS TISSUES VIA UNIAXIAL STRESS RELAXATION TESTS

John Z. Wu, Robert G. Cutlip, and Ren G. Dong
National Institute for Occupational Safety and Health,
Morgantown, WV 26505, USA. email: jwu@cdc.gov

INTRODUCTION

Using traditional experimental methodologies [1,2,3], the skin has to be separated from the subcutaneous tissues in order to determine the tissues' viscoelastic properties. Thus, the complex collagen fiber network in soft tissue could be damaged when the skin is separated from the subcutaneous tissue. Therefore, the viscoelastic properties of the skin and subcutaneous tissues measured using isolated samples may be different from those in physiological conditions. The purpose of the present study is to estimate the viscous behaviors of the skin and the subcutaneous tissues using composite tissue specimens.

METHODS

In a creep test using a specimen of skin/subcutaneous tissue composite, dependence of the total tissue strain [$\varepsilon(t)$] on the strain contributions from skin and subcutaneous tissues is derived as:

$$\varepsilon(t) = \gamma_s \varepsilon_s(t) + \gamma_f \varepsilon_f(t) \qquad (1)$$

where γ_s and γ_f are the skin and subcutaneous tissue thickness ratios, respectively. The corresponding normalized creep function of the tissue composite [$j(t)$] is related to those of skin and subcutaneous tissues [$j_s(t)$ and $j_f(t)$] by:

$$j(t) = \alpha\, j_s(t) + \beta\, j_f(t) \qquad (2)$$

where α and β are parameters depending on the thickness ratios and elastic stiffness of the skin and subcutaneous tissues. If two creep tests (A and B) are performed using specimens of different thickness ratios of the skin and subcutaneous tissues, they will result in two distinct creep curves. Assuming that these two tissue samples are taken from two locations close to each other from the same animal, the mechanical characteristics of the skin and subcutaneous tissues in specimen A should be similar to those in specimen B. Therefore, the normalized creep functions of the skin and subcutaneous tissues [$j_s(t)$ and $j_f(t)$] can be solved from:

$$j(t)^A = \alpha_A j_s(t) + \beta_A j_f(t), \qquad (3)$$
$$j(t)^B = \alpha_B j_s(t) + \beta_B j_f(t)$$

Because of scattering of test data of soft tissues, multiple tests are to be performed using tissue samples with different skin/subcutaneous thickness ratios and the equations are to be solved using a least square method. Viscoelastic properties of soft tissues in compression are usually obtained via stress relaxation tests, because the stress relaxation tests are, technically, much easier to perform than the creep tests. The proposed procedure is composed of four steps: (1) perform stress relaxation tests using skin/subcutaneous composite specimens, (2) convert the stress relaxation functions to the corresponding creep functions using Laplace transformations, (3) determine the creep functions of skin and subcutaneous tissue using the proposed method, and, finally, (4) convert the creep functions of the skin and subcutaneous tissues to their corresponding stress relaxation functions using inverse Laplace transformations. The proposed procedure has been applied to determine the viscous properties of the skin and subcutaneous tissues of pig. The tissue samples were collected from the palmar surface of the front feet of a pig (Landrace-Yorkshire-Duroc hybrid).

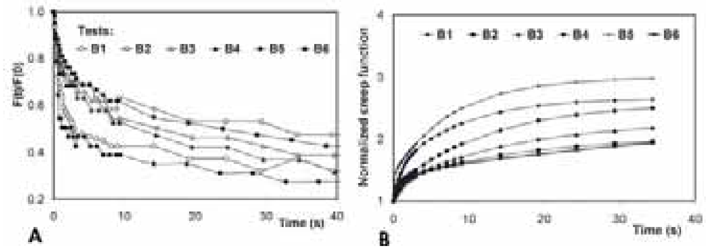

Figure 1: A: The stress relaxations of skin/subcutaneous composite specimens. B: The corresponding normalized creep functions.

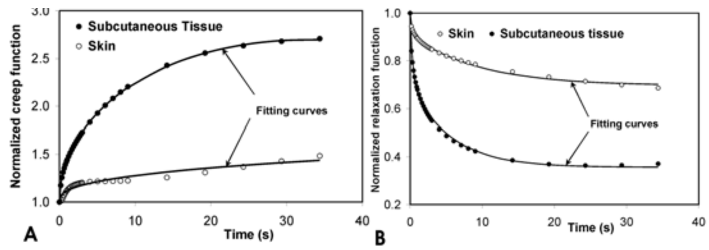

Figure 2: A: The normalized creep functions of the skin and subcutaneous tissues. B: The corresponding stress relaxations.

RESULTS AND DISCUSSION

The six stress relaxation tests were conducted under unconfined compressions using tissue specimens of different skin/subcutaneous thickness ratios (Fig 1A). The stress-relaxation curves have been converted into their corresponding normalized creep functions (Fig. 1B). Using the proposed procedure, the creep and stress-relaxation curves of the skin and subcutaneous tissues were derived, as shown in Figs. 2A and B.

CONCLUSIONS

Using the proposed test procedure, we can simultaneously estimate the viscous properties of the skin and subcutaneous tissues without separating them prior to testing, such that the soft tissue composite specimens reflect physiological loading conditions more reasonably than the specimens of isolated skin and subcutaneous tissues.

REFERENCES

1. Pan, L et al. *Ultrasound Med Biol* **24**, 995-1007, 1998.
2. Miller-Young J et al. *J Biomech* **35**, 1523-1532, 2002.
3. Gennisson JL et al. *Ultrason Ferroelectr Freq Control* **51**, 980-989, 2004.