ANALYSIS OF FINGERTIP/PROBE INTERACTION IN THE VIBROTACTILE TESTS

J. Z. Wu, R.G. Dong, A.W. Schopper

National Institute for Occupational Safety and Health, Morgantown, West Virginia, USA

Introduction

The measurement of vibrotactile perception threshold has been often used to assist in the diagnosis of the severity of peripheral neuropathy associated with hand-arm vibration syndrome (Lindsell and Grifûn, 1999). The vibration perception threshold has been found to depend on the contact force, vibration frequency and magnitude, and finger skin temperature. However, the biomechanics of the tactile sensation underlying these phenomena remains unclear. Since the mechanoreceptors embedded in the skin sense their mechanical environment, the variations in the test conditions will influence the stress/strain distributions in the soft tissues and thus affect the reliability of the test results. The purpose of the present study is to analyze, theoretically, the effects of decoupling of the probe from the skin surface on vibrotactile threshold.

Method

The mechanical responses of the ûngertip are analyzed using a multilayered two-dimensional ûnite element model (Fig. 1a) (Wu et al., 2003). The ûngertip is assumed to be composed of a skin layer representing epidermis and dermis, subcutaneous tissue, bone, and nail. The dimensions of the ûngertip are assumed to be representative of the index ûnger of a male subject. The skin tissue is assumed to be hyperelastic and linearly viscoelastic. The subcutaneous tissue is assumed to be a biphasic material composed of a ûuid phase and a hyperelastic solid phase. The nail and the bone are considered as linearly elastic. The numerical simulations have been designed to mimic the experiments conducted by Goodwin et al. (1989). The ûngertip is assumed to be ûxed on the nail surface, while a steel probe is subjected to a vertical sinusoidal motion (Fig. 1b). The proposed model is used to predict the time-dependent deformation proûle of the skin surface, the time histories of the contact force, and the time-dependent distributions of stress/strain within the soft tissues of the ûngertip. Since ûngertips are believed to sense the spatial summations of stimuli (Goble et al., 1996), we have further analyzed the variations in the spatial summations of

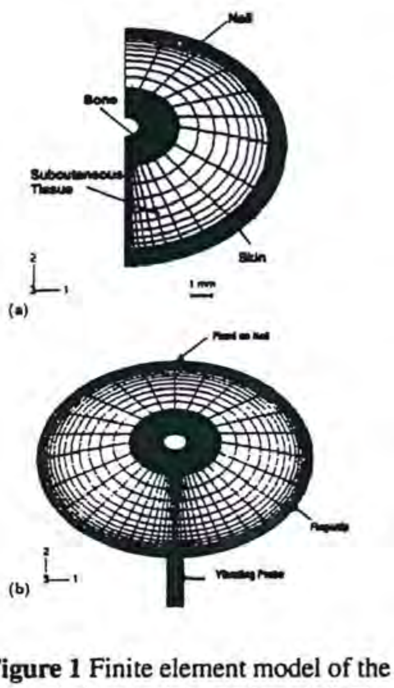


Figure 1 Finite element model of the ûngertip/probe interaction. (a) The ûngertip model. (b) The modeling of the response of a ûngertip to repeated loading.

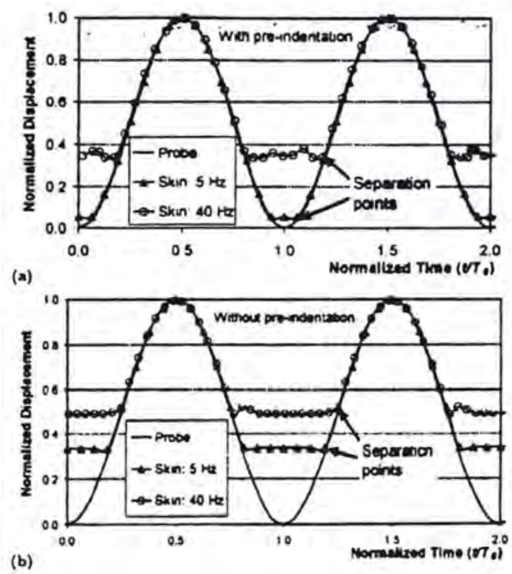


Figure 2. Predicted skin surface displacement history compared with the sinusoidal movement prescribed on the probe for tests with two vibrating frequencies. (a) with pre-indentation; (b) without pre-indentation.

the vertical deformation, horizontal and vertical strains, u_2, E_{11}, and E_{22}, respectively, within soft tissues around the stimulus spot.

Results

The prescribed displacements of the probe are compared with the steady-state displacement responses at the skin surface at two different vibrating frequencies (f =5 and 40 Hz) as derived from the tests with and without pre-indentations in Figs. 2a and 2b, respectively. In these ûgures, the displacement is normalized with respect to peak-to-peak (p–p) displacement of the probe, such that the instances of separation between the probe and the skin surface can be compared with each other. The time has been normalized to the period of sinusoidal displacement, t_0. We further analyzed the distributions of the tissue strains at a depth of 0.8 mm under the skin surface where the mechanoreceptors are located. Typical distributions of vertical displacement (u_2) horizontal and vertical strains (E_{11} and E_{22}) are depicted in Fig. 3. The variations in spatial summations of these variables have been calculated numerically to analyze the effects of probe/skin decoupling on fingertip sensitivity to the vibrations. We found that the variations associated with u_2 and E_{22} for the tests with pre-indentation are greater than those without pre-indentation by factors of 20%–50%; while the variation associated E_{11} shows little variation.

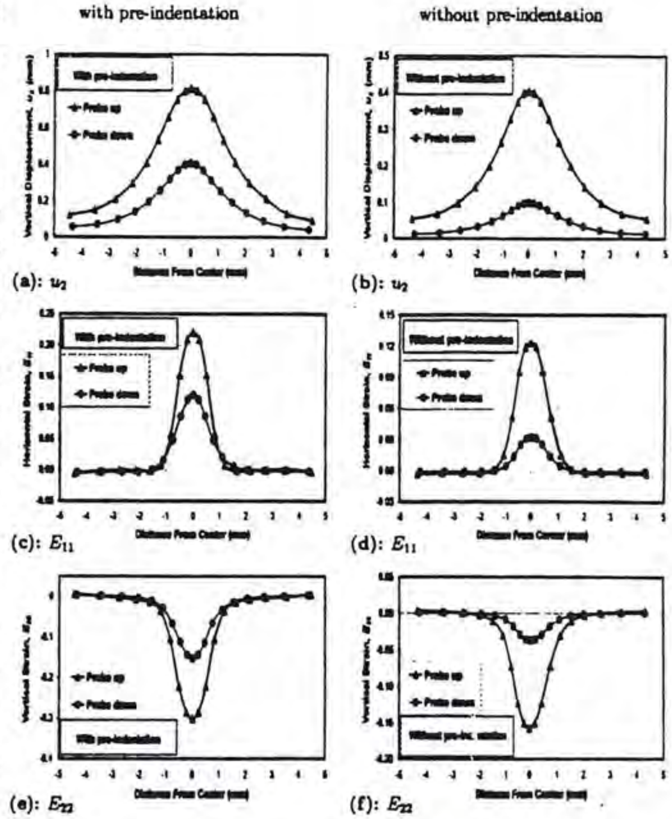


Figure 3 Distributions of vertical displacement, u_2, horizontal and vertical strains, E_{11} and E_{22}, respectively, at a depth of 0.8 mm within the soft tissue of ûngertip at probe-up and probe-down positions.

Discussion and Conclusions

The numerical simulations show that, for certain vibration frequencies and amplitudes, the probe can decouple from the skin surface during sinusoidal motion, which is consistent with the experimental observations by Goodwin et al. (1989). Since the mechanoreceptors embedded in the skin sense their mechanical environment, the separation of the probe from the skin surface during vibrotactile tests will inûuence the stress/strain in the skin and thus inûuence the reliability of the results. Our numerical results suggest that the decoupling of the vibrating probe from the skin surface will reduce the variations in the strains in the skin which the mechanoreceptors can sense and, consequently, a ûnger's sensitivity to vibration pulses might be reduced.

Bibliography

1 Lindsell, C. and Grifûn, M.J. 1999. Thermal thresholds, vibrotac-tile thresholds and ûnger systolic blood pressures in dockyard workers exposed to hand-transmitted vibration. Int Arch Oc-cup Environ Health, vol 72, pp 377–386.

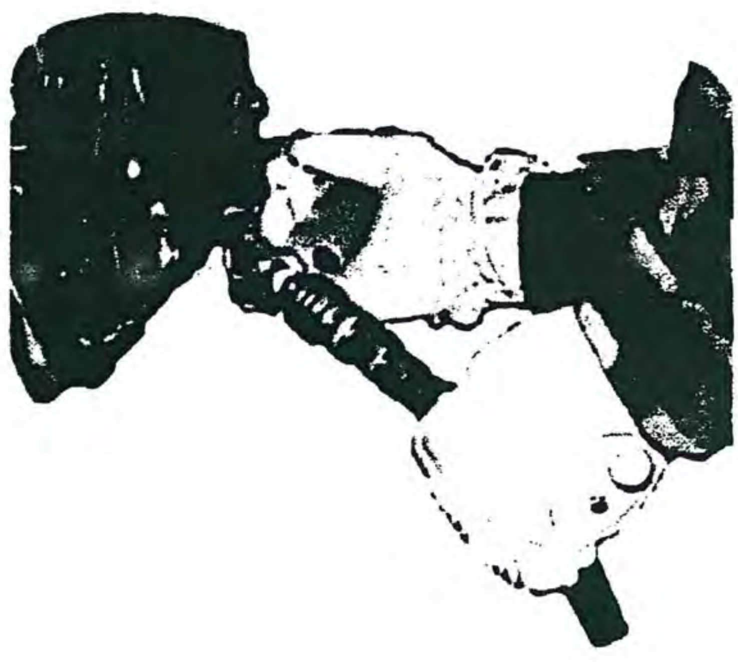
2 Goble, A.K., Collins, A.A., and Cholewiak, R.W. 1996. Vibrotactile threshold in young and old observers: the effects of spatial summation and the presence of a rigid surround. J Acoust Soc Am, vol 99, pp 2256–2269.

3 Goodwin, A.W., John, K.T., and Darian-Smith, I. 1989. Skin proûles during sinusoidal vibration of the ûngerpad. Exp Brain Res, vol 77, pp 79–86.
4 Wu, J.Z., Dong, R.G., Schopper, A.W., and Smutz, W.P. 2003. Analysis of skin deformation profiles during sinusoidal vibration of fingerpad. Ann Biomed Eng, vol 31, pp 867-878.

10th International Conference on Hand-Arm Vibration

7-11 June 2004

Flamingo Hilton Resort
Las Vegas, Nevada, USA



Conference Program
&
Preconference Proceedings