MODELING OF BIOMECHANICS OF TACTILE SENSATION ON FINGERTIPS

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INTRODUCTION

Tactile perception threshold measurement has been widely used to diagnose the severity of peripheral neuropathy, for example, hand-arm vibration syndrome. The study of biomechanics of the fingertips is vital to enhance an understanding of mechanism of tactile sensation and sensory thresholds. The reported fingertip models (e.g., Phillip and Johnson, 1981; Srinivasan and Dandekar, 1996) do not incorporate the nonlinear and time-dependent effects associated with the anatomical substructures and tissue material properties. The purpose of the present research was to develop a finite element model to simulate the mechanics of tactile sensation of a fingertip.

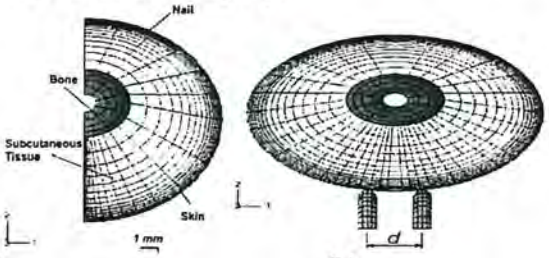


Figure 1: Finite Element Model. **(a):** Multi-layered fingertip model. **(b):** Two-point discrimination (2PT) test

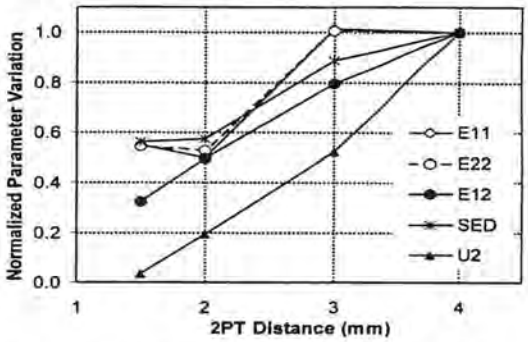
METHODS

The biomechanics of tactile sensation of a fingertip were analyzed using a multi-layered two-dimensional finite element model, as shown in Fig.1a. The fingertip was assumed to be composed of a skin layer, subcutaneous tissue, bone, and nail. The fingertip dimensions were assumed to be representative of index finger of a male subject. The skin tissue, including epidermis and dermis, was assumed to be hyperelastic and linearly viscoelastic. The subcutaneous tissue was assumed to be a biphasic material composed of a fluid phase and a hyperelastic solid phase. The nail and the bone were considered as linearly elastic. Numerical tests were performed to study the mechanics of tactile sensation of the fingertip in two-point (2PT) discrimination tests (Fig.1b). The fingertip was fixed on the center of nail surface, while two indentors (each with a circular contact surface and thickness of 1 mm) were used to deform the skin surface of the fingertip by 1 mm within a ramping period of 1 s. Four numerical tests with different spacing between the indentors (d = 1.5, 2.0, 3.0, and 4.0 mm) were performed. The analyses were performed to compute the displacement, stress, and strain fields within the soft tissue at the state of maximum depression. The mechanical states (stress/strain) of the tissue at a depth of 0.75 mm from the undeformed skin surface, where the Merkel cell receptors are located, were analyzed in the study.

RESULTS AND DISCUSSION

The simulation results reveal that differences in horizontal and vertical strains (E11 and E22, respectively) and strain energy density (SED) developed in the skin at the contact points and at the geometric center of the fingertip vary only slightly with a decrease in the indentor spacing from 4.0 to 3.0 mm (Fig. 2). These differences, however, decrease considerably with a further decrease in the indentor spacing from 3.0 to 2.0 mm. The corresponding differences in the vertical displacement (U2) and shear strain (E12), however, decreased almost linearly with a decrease in the indentor spacing from 4.0 to 1.5 mm.

Figure 2: Normalized variations of horizontal (*E11*), vertical (*E22*) and shear strains (*E12*), vertical displacement (*U2*), and strain energy density (*SED*) as a function of 2PT spacing. The



normalized variations were evaluated by [f (contact point of indentor)-f (geometry center)]/ f (contact point of indentor).

SUMMARY

The present analysis suggest that, assuming mechanoreceptors in the dermis sense the stimuli associated with normal strains (E11 and E22) and train energy density (SED) rather than those associated with shear train (E12), the threshold of 2PT discrimination test for the fingertip may lie between 2.0 and 3.0 mm. This analysis is consistent with the experimental observations by Perez et al. (2000) who reported an average 2PT discrimination distance of 2.1 mm in tactile sensation threshold tests of the index finger.

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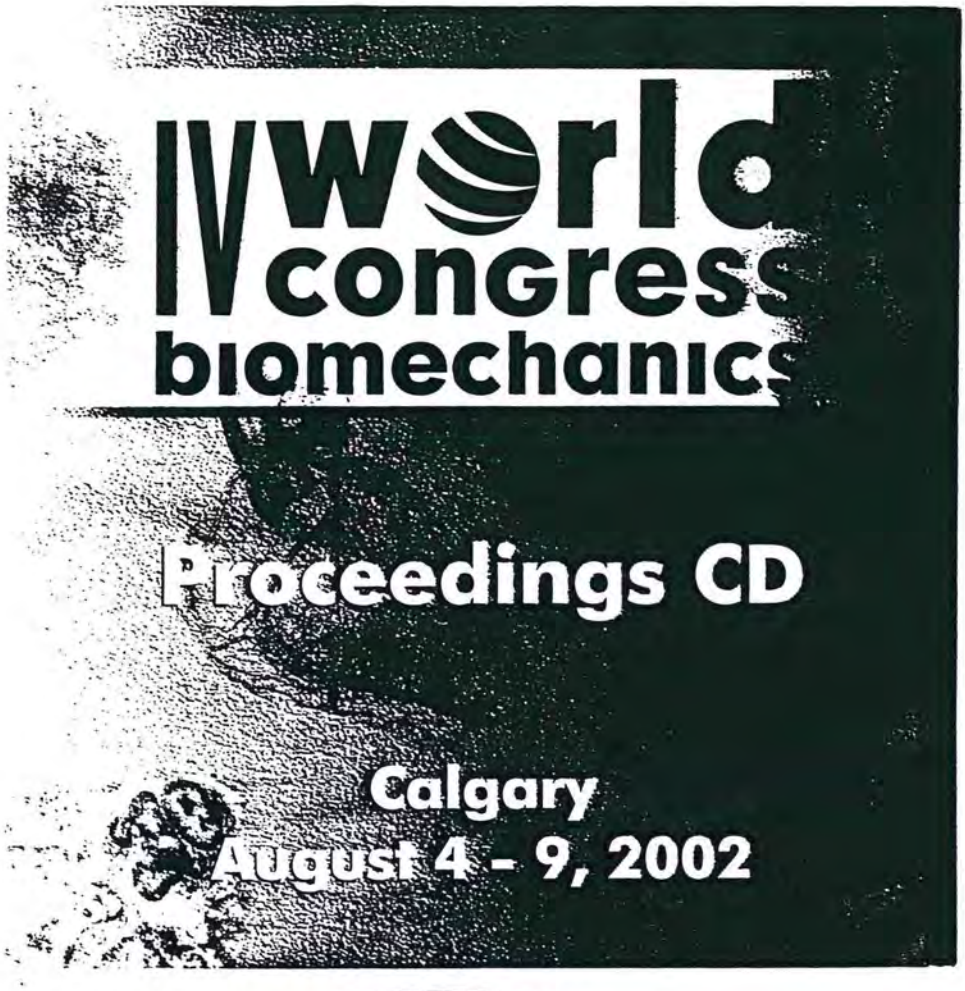
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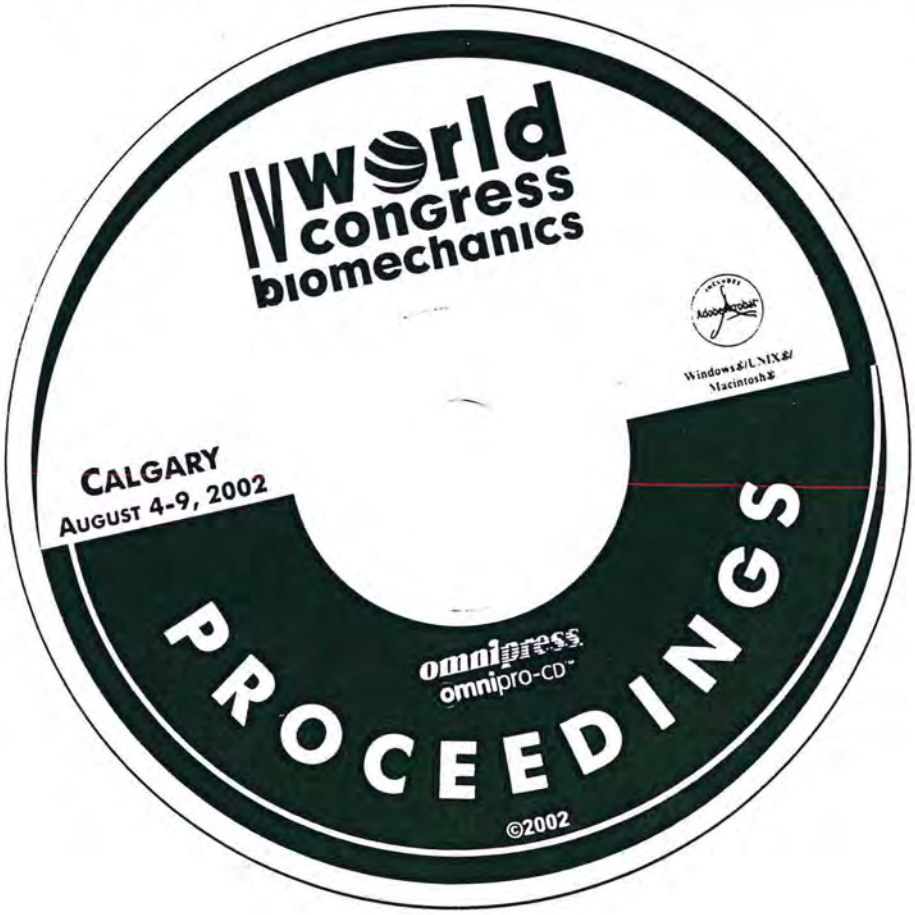
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