

# FREE VIBRATION OF A FINGERTIP: FINITE ELEMENT ANALYSIS

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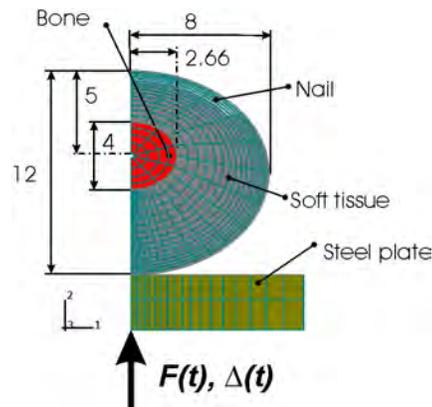
## INTRODUCTION

An extended occupational exposure to hand-transmitted vibration, arising from the operation of hand-held power tools, has been associated with the development of an array of vascular, sensorineural and musculoskeletal disorders. The vibrotactile perception threshold (VPT) measurement technique is widely used to diagnose the sensory neuropathy of the hand induced by an extended exposure to vibrations. The measured values of VPT have been reported to depend on the contact force, vibration frequency and magnitude, and the temperature of the finger skin [1]. Although the measured values of VPT responses of fingertips have been widely spread, no attempts have been made to develop adequate analytical models to study the mechanics of tactile sensation. This study proposes a finite element model of a human fingertip to study its responses to impinged vibration.

## METHOD

A two-dimensional finite element (FE) model of a fingertip is developed to study its deformation-dependent vibration responses. The model is composed of linearly elastic bone and nail, and nonlinearly elastic and visco-elastic soft tissue. The fingertip was assumed to be symmetric (Fig. 1). The skin tissue is assumed to be in contact with a linearly elastic, smooth steel plate, representing the vibrotactile probe. The dimensions of the fingertip model are assumed to be representative of the index finger of a male subject. The material parameters of the soft tissues, bone, and nail are taken from the published experimental data [2,3]. The fingertip tissue is subjected to varying levels of static deformations and contact force by displacing the contact plate vertically. At  $t=0$ , the plate is considered to be in contact with the fingertip skin surface with negligible resultant contact force. The

contact plate is then displaced upwards to achieve a predetermined value of the tissue deformation ( $\Delta$ ) within a ramping period of  $T_c$  ( $=1$ s). The FE simulation is performed to determine the free-vibration characteristics of the fingertip corresponding to different tissue deformation levels ( $\Delta = 1.5, 2.0, 2.5,$  and  $3.0$  mm).

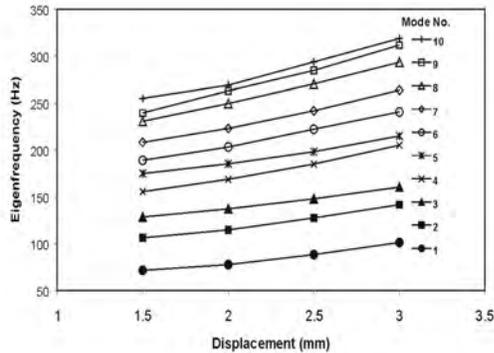


**Figure 1:** Finite element model of a fingertip

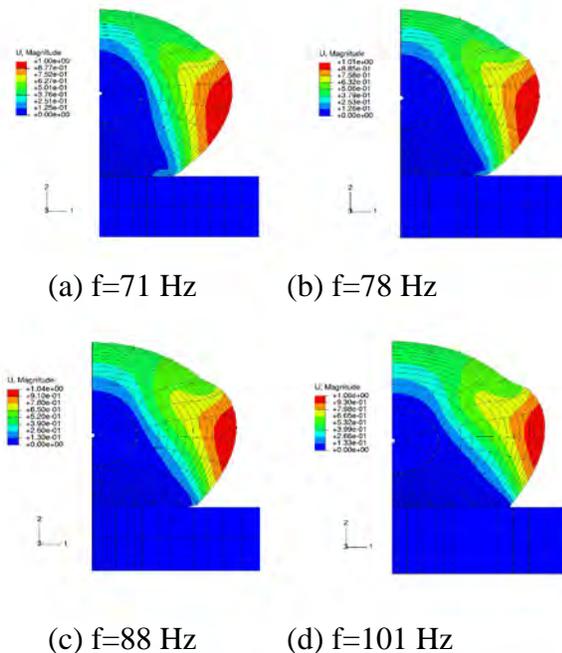
## RESULTS

The modal analysis of the fingertip model was performed using the tangential stiffness of the tissue corresponding to the maximum deformation at  $t=T_c$ . The free vibration analysis of the fingertip model, as expected, resulted in a large number of natural modes. Considering that most power tools generate dominant vibration in the frequency range of 25-320 Hz [4,5], the first ten eigenfrequencies of the fingertip model were extracted corresponding to each static deformation. Fig. 2 illustrates the variations in the modal frequencies as a function of the static tissue deformation. The natural frequencies corresponding to the extracted modes lie in the 40 Hz to 320 Hz frequency range. The eigenfrequencies corresponding to the selected modes increase considerably with increase in the magnitude of the tissue compression or pre-load. The eigenfrequency corresponding to a specific mode

tends to increase almost linearly with the magnitude of the static deformation, irrespective of the mode of vibration. The variations in the static deformation also affect the deformation patterns of the fingertip corresponding to the selected modes (Figs. 3a-d).



**Figure 2:** Static deformation dependence of the modal frequencies.



**Figure 3:** Influence of static deformation on the deflection pattern corresponding to the first mode: (a)  $\delta = 1.5$ ; (b)  $\delta = 2.0$ ; (c)  $\delta = 2.5$ ; and (d)  $\delta = 3.0$  mm.

## DISCUSSION AND CONCLUSIONS

The simulation results suggest that the free vibration response of the fingertip is strongly dependent upon the static

deformation. The eigenfrequency corresponding to a specific mode tends to increase considerably with the increase in the static deformation or the contact force. This phenomenon is attributed to the nonlinear elasticity of the soft tissues. The fingertip exhibits deformation dependent progressively hardening stiffness with increasing static deformation or contact force (results not shown). Consequently, the fingertip model yields deformation-dependent modal deflection patterns and frequencies. Similar phenomenon has also been reported by [5], who observed that the resonant frequencies of the hand-arm system increase with increase in the grip force.

In the present study, a two-dimensional finite element model is developed to study modal characteristics of a prestressed fingertip. The proposed model is developed on the basis of the physical properties of the soft tissue and the anatomical structures of the fingertip, and is capable of predicting modal characteristics of the fingertip under the deformed or loaded conditions. Our results suggest that the modal vibration characteristics of the fingertip are deformation-dependent; the eigenfrequencies of the fingertip increase with the increasing pre-load. The present study represents a preliminary effort in developing a structural model of the fingertip that incorporates its anatomical structure and nonlinear and time-dependent visco-elastic properties of the soft tissues.

## REFERENCES

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