DYNAMIC RESPONSES OF A FINGERTIP TO VIBRATION - 3D FINITE ELEMENT ANALYSIS

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Introduction

Although the exact mechanisms underlying vibration white finger (VWF) are not clear, it has been speculated that VWF is associated with variations of the blood flow patterns due to the physical damage and/or degeneration in neural and vascular tissue caused by vibration loading [1]. Excessive dynamic deformation of the soft tissues in the fingertip under vibration loading is believed to induce multiple occupation-related hand/finger disorders. However, the in vivo distributions of the dynamic stress/strain of the tissues in the fingertip under vibration conditions have not been studied because they cannot be measured experimentally to date. The goal of this study is to analyze, theoretically, the location and frequency-dependent dynamic deformation of the soft tissue in the fingertip during vibration exposures.

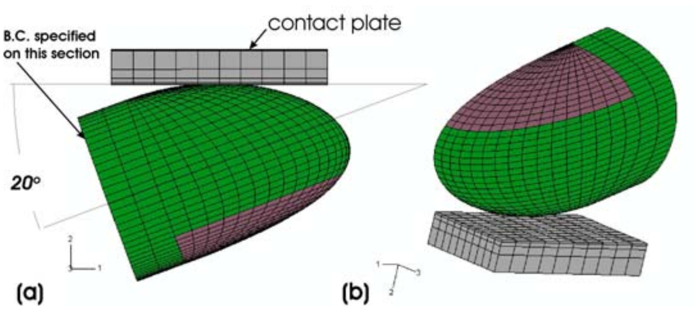

Figure 1: FE model of the fingertip in contact with a flat surface. (a): side view. (b): perspective view. The fingertip is in contact with a flat plate with a contact angle of 20^{o}.

Methods

The fingertip considered in the model is the distal phalanx, the portion from the distal end of the fingertip to the distal interphalangeal (DIP) joint articulation (Fig. 1). The external shape of the fingertip was determined using a smooth mathematical surface fitting to the observed fingertip shapes. The fingertip surface was then scaled to the dimensions of a typical male index finger: length 25 mm, width 20 mm, and height 18 mm. The fingertip was approximated to be symmetric, such that only a half of the fingertip was considered in the FE modeling. The fingertip was assumed to be composed of outer and inner skin layers, subcutaneous tissue, bone, and nail. The soft tissues (inner skin layer and subcutaneous tissues) were assumed to be nonlinearly elastic and viscoelastic, while the bone, nail, and outer skin layer were considered as linearly elastic. The simulations were conducted using a displacement-controlled protocol in two stages. First, the fingertip was statically pre-compressed. The contact plate was first displaced towards the finger to achieve a predetermined value of tissue deformation (i.e., 0.5, 1.0, 1.5, and 2.0 mm). Second, the steady-state dynamics responses of the fingertip were analyzed using a linear perturbation procedure. The fingertip was subjected to a continuous harmonic excitation (magnitude 0.5 mm) from the contact interface. The dynamic analysis was performed in a frequency domain ranging from 16 to 2000 Hz. The frequency-dependent distributions of the vibration magnitude and dynamic strain magnitudes in the soft tissues are investigated.

Results

Typical simulation results for the frequency-dependent distributions of the vibration magnitude in the soft tissues are shown in Fig. 2 (figures show the results with a pre-compression of 2.0 mm). The vibration magnitude at the contact surface is 0.5 mm (specified) for all frequencies, while the vibration magnitudes in the soft tissues are location- and frequency-dependent. It is clear that the fingertip has a major resonance around 125 Hz, at which the vibration magnitudes in the soft tissues are over four times greater than that of the contact plate (0.5 mm). It is interesting to observe that, at this resonant frequency (125 Hz), the soft tissues at the tip has the maximal vibration magnitude while the regions near the contact interface participate less in the vibrations. For frequencies greater than 250 Hz, the vibrations tend to be concentrated in the tissues near the contact interface.

Discussion

The present simulation results show that the effects of vibration on soft tissue are region dependent, with the soft tissues near the nail bed displaying much less dynamic deformation than those in the finger pad, close to the point of contact with the vibrating source. In addition, no resonance of the fingernail was observed in the frequency range of power tools. Based on the current results, one would speculate that alterations in blood flow in the fingertips would be more prevalent, and occur earlier in the soft tissue of the fingerpad than in the vessels round the nail bed. These model predictions on the dynamic deformation distribution within the tissues are consistent with the physiological data collected from workers with VWF [2,3]. We have also examined the effects of compression on finger vibration mode. The fingertip was found to have a major resonance around 100 Hz, which increases with increasing pre-compression. These simulation results are consistent with the experimental observations of the mechanical impedance of the fingertip [4]. The modal shapes of the fingertip at the resonances cannot be determined experimentally at this time. Our results indicated that this resonant mode (around 100 Hz) of the fingertip is associated with amplified vibration at the tip (Fig. 2). Thus, exposure to vibration frequencies close to the resonance may result in an increase in blood vessel deformation at the very tip of the finger, making these frequencies more likely to induce injury.

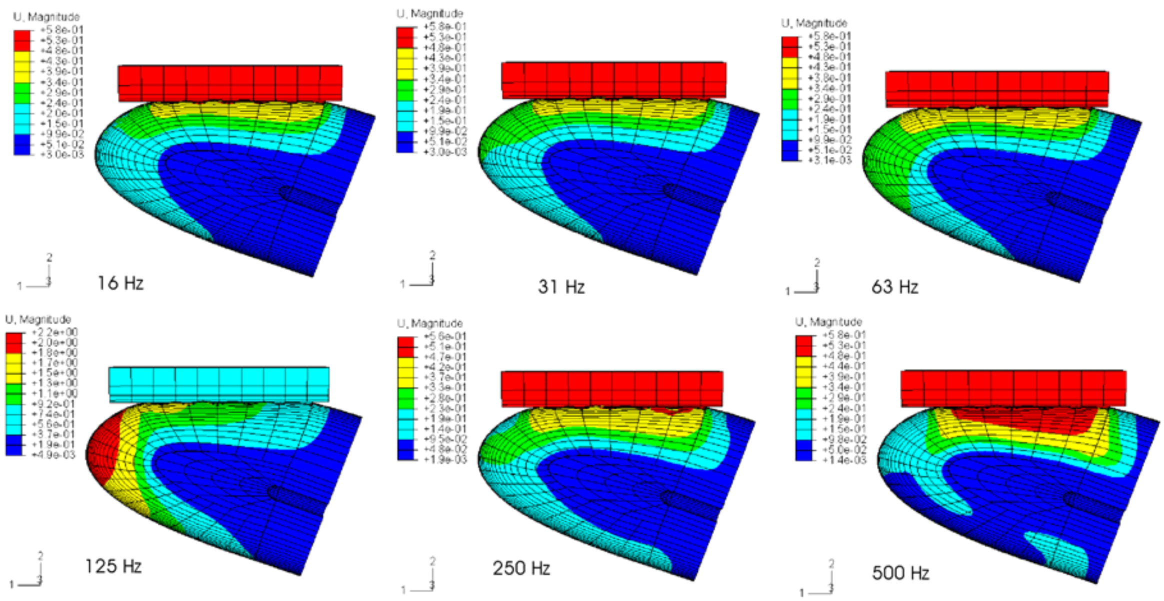

Figure 2: The distributions of the vibration magnitude in the longitudinal section for six different vibration frequencies (f= 15.6, 31.3, 62.5, 125, 250, and 500 Hz). The fingertip is pre-compressed by 2.0 mm before being subjected to harmonic vibrations (magnitude 0.5 mm).

References

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