3D FINITE ELEMENT SIMULATIONS OF THE DYNAMIC INTERACTION BETWEEN A FINGERTIP AND A FLAT SURFACE

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INTRODUCTION

The contact interactions between hands and handles may influence the loading distributions in musculoskeletal systems while operating power tools (Gurram et al., 1995). Many occupation-related disorders in the hand and fingers are believed to be associated with the contact pressure between the fingers and the tool handle. The contact interactions between fingers and handle may also interfere with grasp stability, thereby affecting the manipulations of hand-held tools (Birznieks et al., 1998). The purpose of the present study is to develop a 3D finite element (FE) model for the fingertip to simulate the nonlinear and time-dependent responses of a fingertip to static and dynamic loadings and to compare the theoretical predictions with the published experimental data.

METHODS

The fingertip considered in the model is the distal phalanx, the portion of the finger distal to the distal interphalangeal (DIP) joint articulation, as shown in Fig. 1. The external shape of the fingertip was determined using a smooth mathematical surface fitting to the digitized fingertip shapes. The fingertip model has a length of 25 mm, a width of 20 mm, and a height of 18 mm, which are considered to be representative for a typical male index finger. The fingertip was assumed to be symmetric, such that only a half of the fingertip was considered in the modeling. The FE model incorporates the essential anatomical structures of a finger: skin layers (outer and inner skins), subcutaneous tissue, bone, and nail. The soft tissues (inner skin and subcutaneous tissue) are considered to be nonlinearly viscoelastic, while the hard tissues (outer skin, bone, and nail) are considered to be linearly elastic. The simulations were performed using the commercial FE software package Abaqus (version 6.5). Using the proposed model, we have studied the dynamic contact interaction between the fingerpad and a flat surface. The fingertip was subjected to four different loading/unloading time-histories, as shown in Fig. 2.

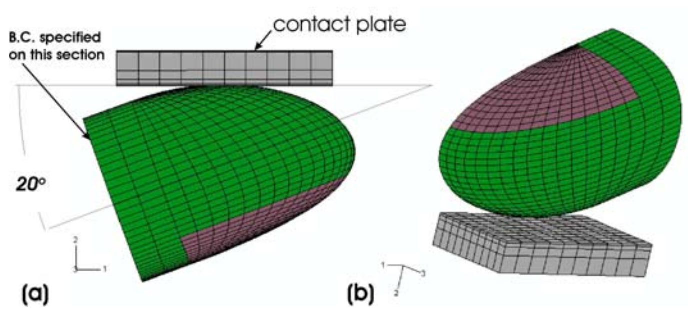

Figure 1: FE model of the fingertip in contact with a flat surface. (a): side view. (b): perspective view. The fingertip is in contact with a flat plate with a contact angle of 20°.

RESULTS AND DISCUSSION

The predicted time-histories of the force responses agree well in trends with the corresponding data (Wu et al., 2003) for the dynamic contact of the fingertip with the flat surface (Fig. 3). At the moment when the compressed displacement was suddenly released from 2 mm to 1 mm, the model predicts that the contact force reaches about zero and then recovers to higher levels. These simulation results are a little different from the experimental observations, which showed higher minimum force values. The difference between the theoretical prediction and experiment data at that particular point is likely due to artifacts in the experiments. The small contact forces (< 5 g) observed in the experiments may be caused by the inertia of the indentation plate, while the simulations were performed using a quasi-static scheme in which the inertial effects of the contact platen were excluded.

SUMMARY/CONCLUSIONS

In the present study, we proposed a novel 3D FE fingertip model, which contains realistic anatomic micro structures and nonlinear viscoelastic material properties of the soft tissues. The model predictions on the time-dependent force responses of the fingertip subjected to the dynamic contact with a flat surface agree well with the published experimental observations.

REFERENCES

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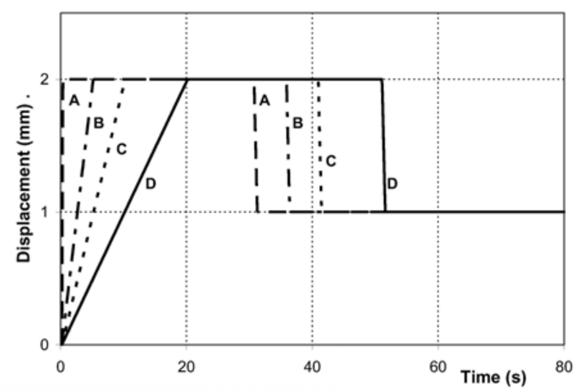
DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.



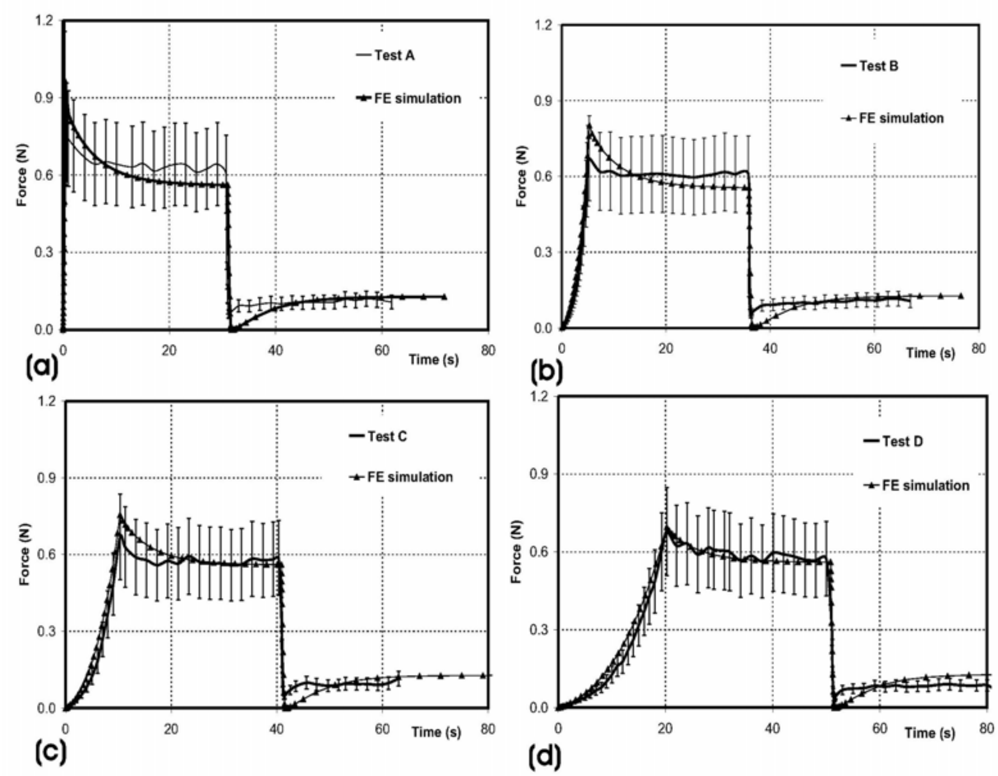


Figure 2: The flat contact plate was prescribed to four (A, B, C, and D) different displacement time-histories in the simulation

Figure 3: The comparison of the predicted time-dependent force responses with the experimental data (Wu et al., 2003)