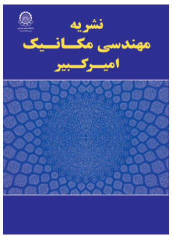

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Numerical Analysis of Temperature Distribution in a 3 Dimensional Magnetic Resonance Image-Based Human Finger Model under Severe Cold Conditions

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ABSTRACT: Frostbite is severest form of cold injury that can have serious consequences which may include loss of some important limbs such as digits, ears, cheek and nose which are far from heart as main heat source in human body. Therefore, in this article, it has been tried to simulate the temperature distribution and find the starting time of frostbite in a human finger as a member that is sensitive to cold stress with a realistic approach. In this research, anatomical data has been extracted from magnetic resonance images which approximate bone, soft tissues and vessels volume independently. The approach that is presented for converting the magnetic resonance images to 3-D finite element model is one of novelty of this inquiry. A coupled thermo-fluid model is applied to simulate a finger exposed to cold weather. The effect of heat conduction, metabolic heat generation, heat transport by blood perfusion, heat exchange between tissues and large vessels are considered in energy balance equations. Environmental situations such as ambient temperature and wind speed and also glove thermal resistance have been investigated and compared to each other. Results show good agreement with experimental data.

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1- Introduction

In this paper, in spite of most previous works, like as Shitzer et al. [1-2] that presented one- two-dimensional models or Manda [3] and Fallahi et al. [4] that proposed simple 3-D models, in this study, and, based on digit's anatomy, a real 3-D model of human finger is presented and thermal behavior of finger is investigated in severe cold conditions. Extracting a 3-D model from Magnetic Resonance Images (MRIs) and identifying sub-layers of finger, including bone and soft tissues, can be considered as an important novelty of this study. Finding the vessels directions and their effects on temperature profiles has also increased the reliability and ability of simulations. Furthermore, the effects of parameters such as environmental conditions and hand-covering on the temperature distribution during cold conditions are investigated and compared to each other.

2- Methodology

2- 1- Geometry and tissues

In this inquiry, a finger model is developed with the help of finite element techniques along with blood flow through the model to represent the real human finger as accurate as possible. The finger geometry extracted from MRI images by a novel approach. An image-processing software (Mimics) and some intermediate software (Meshmixer, Autodesk Inventor, 3Ds Max) were employed to construct a 3-D biological model. Several optimization and geometrical modeling techniques are integrated for the construction of the model. The method is schematically summarized in Fig. 1. The finger is assumed to be a bone core enclosed within the soft tissue layer.

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2- 2- Blood circulation

In this study, blood flows into the finger through two arteries that identified and modeled by using image processing approach and embedded in the geometrical model. Thermal vein effects are also simulated by four small tubes which are located around the bone tissue.

3- Results and Discussion

3- 1- Temperature distribution

Thermal simulations are performed on a real extraction model of MRI images and the temperature distribution through the tissues and blood vessels are obtained. An example of temperature contours of axial and sagittal section of small finger at 50 minutes under the ambient temperature of 5°C and wind speed of 1 m/s is shown in Fig. 2.

On the other hand, Fig. 3 represents the current model fingertip temperature response to Wilson et al. [5] experimental conditions. Wilson et al. [5], induced frostnips in forty five male volunteers by exposing the fingers at -15°C with various wind speeds. The skin freezing point determined by Keatinge and Canon [6] was between –0.53°C and -0.65°C and -0.6°C was used in the current study as skin freezing point. It is observed that the current model endurance times are located at the range of experimental data.

3- 2- Analyzing effective parameters

Environmental conditions such as ambient temperature and wind speed are very influential on the distribution of temperature and rate of freezing of tissues. Therefore, the effects of these two parameters on the temperature distribution

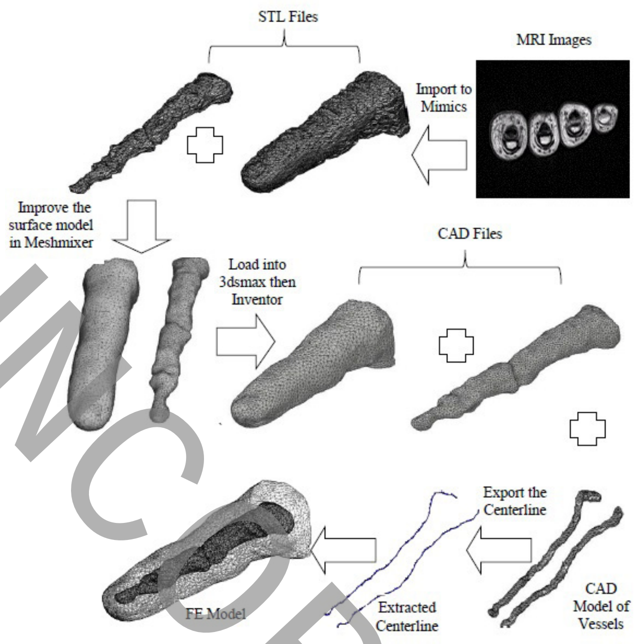

Fig. 1. Flow chart of the geometrical modeling of human finger from MR Images

are investigated and the results are shown in Fig. 4 typically. It can be seen that the lower the ambient temperature and the highest the wind speed, the temperature decreases with more speed and slope, and the risk of frostbite increases.

The proposed method also can be effective in choosing suitable gloves to prevent frostbite. For example, Fig. 5 illustrates the temperature distribution for a small finger with three wears with different thermal resistance at -15 °C and wind speed 10 m/s. It is clear in Fig. 5 that under the same environmental conditions, whatever the glove is used with higher thermal resistance, hands are at a lower risk of frostbite. With this method, depending on the different environmental conditions and different specifications of the fingers belonged to each person, suitable gloves can be selected and used to prevent frostbite phenomena. Also, with a determined glove and environmental conditions, it is possible to predict the onset of cold injury.

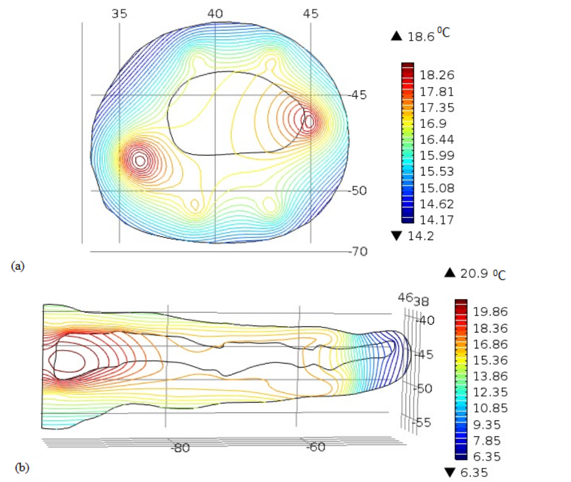

Fig. 2. Isothermal contours at 50 min, in -50C and 1m/s wind speed a)Axial section at 28.5 mm apart from finger base and b) Sagittal section at the middle

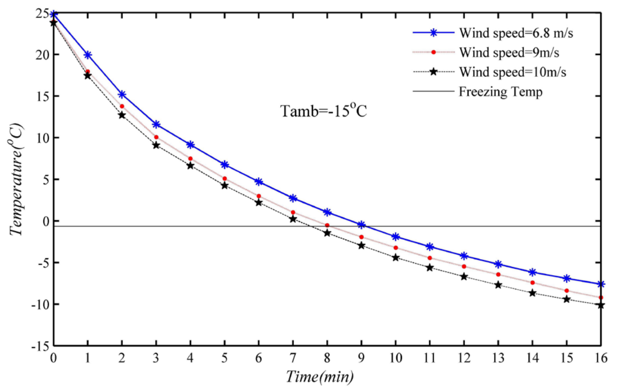

Fig. 3. Temperature distribution in finger-tip under the Wilson et al. [5] conditions at -15oC ambient temperature and different wind speeds

4- Conclusion

In this paper, a method was presented for extracting a 3D model from MRI images. It is a new and effective method that models tissues and blood vessels. The model is most closely resembles the anatomy of human finger. This similarity causes the output of mechanical, thermal, and fluid simulations of biological tissues to fit into experimental data as much as possible. Reducing computational time and better convergence are the advantages of this method. The results show that by using empirical data for the temperature of freezing of the skin, finding the temperature distribution can be a good measure for predicting the onset of frostbite.

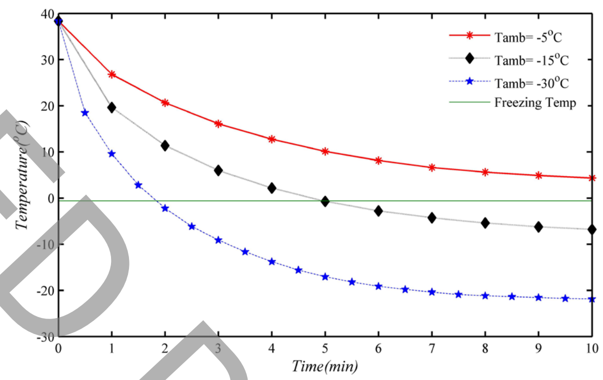

Fig. 4. Temperature distribution in finger-tip at 3m/s wind speed and different ambient temperatures

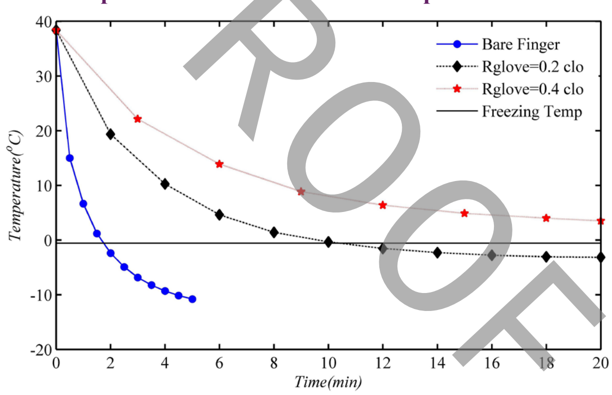

Fig. 5. Temperature distribution in finger-tip at 10 m/s wind speed and -15oC ambient temperatures for different hand wears

Ambient temperature, wind speed and thermal resistance of gloves were the parameters that analyzed in this study. Comparisons show that at low ambient temperatures and high wind speeds, heat loss in the finger and the danger of freezing of tissues is increased. On the other hand, by finding the temperature distribution on the finger in the extreme cold conditions, choosing a suitable glove to prevent frostbite is more efficient and accurate.

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