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Use of the Finite Element Method to Assess Impact of Current on Forearm and Wrist During an Electrical Accident

Michael S. Morse[1], Jennifer S. Morse
[1]Department of Electrical Engineering, University of San Diego, San Diego, CA, 92110

Abstract—**Using geometric primitives, a three dimensional finite element model has been developed to assess the pathway followed by electric current during an electrical accident assuming the entry point for the current was on one hand. Results indicate that the area where the risk of soft tissue injury is greatest is in the wrist region. Current entry on the palm or finger fronts was found to be more likely to yield injury to the median nerve than an entry point on the back of the hand. The lesser injury is theorized to result because of current shielding of the nerve by bone.**

Keywords— **Carpal tunnel, electric shock, electrical injury, median nerve, carpal tunnel syndrome, finite element method**

I. INTRODUCTION

Using FEMLAB software, a three dimensional finite element model of the forearm, wrist and hand was developed based upon a composite of simple geometric primitives. The use of simple primitives created a reasonable approximation of the tissue type and geometry of the lower arm and hand while also allowing for FEM analysis of a much greater three dimensional volume than in prior models in which more complex geometries had been used in the model [1].

Prior FEM research has suggested that current density in a hand involved electrical contact will be elevated in the wrist (carpal tunnel) region [1,2]. The limitation of this earlier work was the mathematical complexity introduced by the use of very complex geometries derived from the visible human project. The mathematical intensity of the FEM limited the earlier analysis to successive three dimensional slices. The goal in the current work was develop a simplified three dimension model that would incorporate hand, wrist, and forearm in a single analysis.

Regarding the risk of tissue injury, the traditional theory is that tissue damage from electrical contact depends mainly on three factors: 1) the pathway and resistance of the tissues traversed by the current, 2) the heat generated by the current and, 3) the duration of the electrical contact [3]. An additional theory suggests that the electric field associated with the current may act on the cell membranes causing cellular atrophy. The greatest injury from an electric field would be anticipated to occur in nerve and muscle cells. [4]

In considering the potential for neural injury, it has been reported that for a 3mm diameter peripheral nerve (in cats), a current of 40 ma applied for a duration of 5 seconds is sufficient to cause lasting disorders in function and structure [5].

Since the wrist is characterized by a reduction in conductive soft tissue as compared to surrounding regions, it would be logical to theorize that current density would be elevated in the wrist. The hypothesis thus tested herein is that the current density or charge exposure to nerve tissue in the region of the carpal tunnel can exceed the threshold required to cause neural damage even when the source current is not high enough to cause more obvious tissue damage (such as entry and exit burns.)

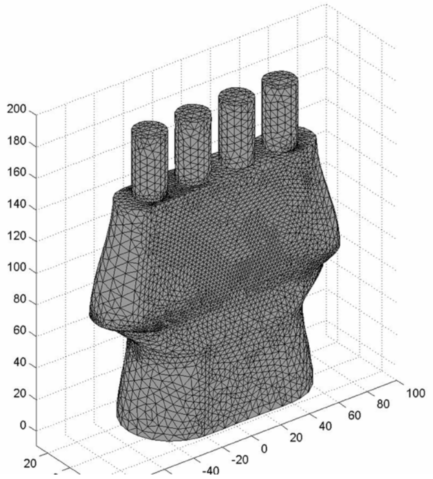

Fig 1. Model employed in finite element analysis.

II. METHODOLOGY

A three dimensional model was developed using geometric primitives such that it was not of so great complexity as to require more memory (real and virtual) than the maximum available (as limited by the 32 bit bus) on the PC upon which the Comsol FEMLAB software was resident. (The matrix inversion required for FEM is of such complexity that the model can very easily exceed the limitations of the computer on which the software resides.) The use of geometric primitives decreases the matrix complexity thus making for an easier solution.

The dimensions of the model were derived from slices taken from the visible human project. The model was limited to four fingers (eliminating the thumb as an entry point) to further simplify the geometry and thus simplify the mathematics. The characterization of tissue types and relative geometry of tissue location was also based on slices taken from the visible human project. Published conductivity of different tissue types was used to parameterize the tissues in the model [6,7]. The mesh generated for the model by the FEMLAB software consisted of 21527 nodes (Fig. 1)

Once the model was established, multiple analyses were run. In each, a 1 ampere current source was applied at a different entry point to simulate an electrical contact. Figure 2 shows the resulting surface current density when the current is applied to the top of the leftmost finger. For each solution, multiple slices were separated and analyzed to determine the percentage of current traversing each tissue type at the level of the slice. (Fig. 3)

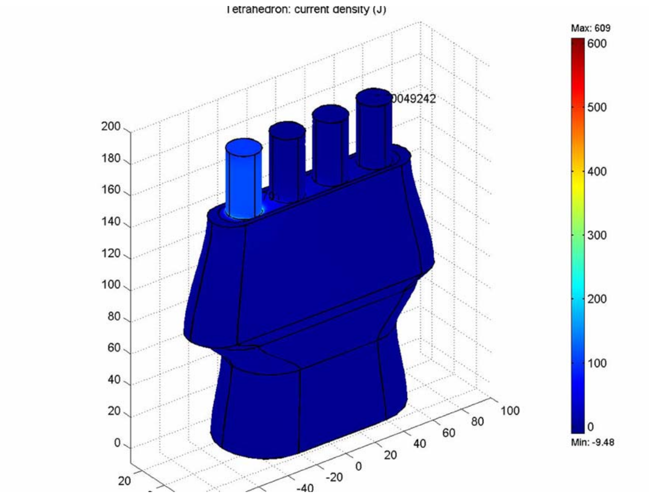

Fig 2. Model showing surface current density with the top of the left-most finger as entry point.

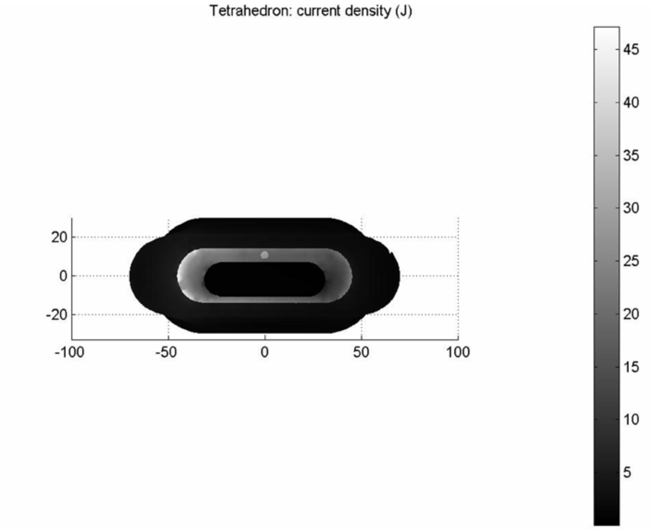

Fig 3. Current density cross-section plot taken at mid-palm level for Fig. 2 simulation. Highest current density is observed in area of soft tissue.

III. RESULTS

Figure 4 shows results typical of the application of one ampere of current to the tip of the leftmost finger. The X axis has been normalize to reflect displacement in centimeters from the mid-wrist region while the Y axis shows current density in the median nerve normalized as a fraction of the current observed in the mid-wrist region.

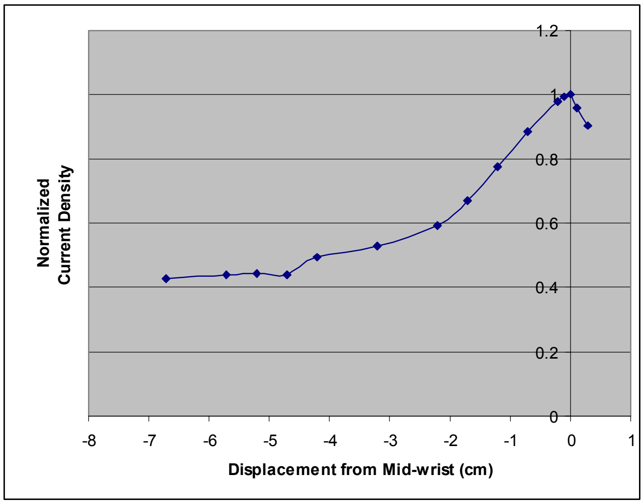

Fig 4 Normalized current density as a function of distance from the mid-wrist region for an approximation of the median nerve.

IV. DISCUSSION

Using the model developed, it was observed that current density calculated for nerve tissue (placed geometrically consistent with the median nerve) would more than double over a distance of 6.7 cm, down the forearm, moving in the direction of the mid-wrist. Current would then fall off slightly when moving distal to the mid-wrist toward the palm. Multiple simulations yielded similar results. Although not shown here, it was observed that when the application of current was on the dorsal portion of a finger, the peak current density in the mid wrist was significantly reduced over simulations in which the current was applied to the palmar side of a finger.

V. CONCLUSION

It has been demonstrated using the model presented herein that current density in the region of the median nerve at the mid-wrist can be more than double that of the current density seen by the median nerve in the forearm. This suggests the possibility of localized neural damage at the level of the mid-wrist even absent other observable injury. The results also suggest that bone acts to protect the carpal tunnel region by shielding the region during an electrical contact involving the dorsal hand. Future research is needed to explore the extent of potential injury associated with varying current levels.

VI. REFERENCES

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