IN VITRO VALIDATION OF THERMAL FINITE ELEMENT ANALYSIS OF CRYOINSULT DELIVERY FOR EMU FEMORAL HEAD NECROSIS

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INTRODUCTION

In ongoing work with the emu as a bipedal animal model of osteonecrosis, lesions are induced by means of a custom built cryoprobe surgically inserted into the femoral head [1]. In order to study the factors governing the size of these lesions, a thermal finite element model has been developed to quantify freeze and thaw rates, as well as freeze front geometry, as a function of operator-controlled parameters during surgery.

Initial validation of the finite element model had been performed in a geometrically simplified agarose preparation [2]. Because this model needs to accurately model the freeze cycle as it occurs intraoperatively, further benchtop testing has been performed in fresh emu femur specimens.

METHODS

Six emu femurs were obtained fresh from an abattoir. PMMA molds were made of the lateral side of each femur and used as a drill guide. A 4 mm diameter drill hole and four 0.8 mm diameter drill holes were drilled through the PMMA. The drill guide was attached to the femur and holes drilled approximately 50 mm into the femoral head. Copper-constantan thermocouples embedded in 0.8 mm diameter tubing were inserted into the four small drill holes.

A custom built cryoprobe [2] was inserted into the femoral head through the main drill hole, and the femur was positioned with its head embedded in a reservoir of 1% agarose, to provide thermal inertia (Figure 1a). A seven-minute freeze from room temperature to –30°C was performed followed by a passive seven-minute thaw. Temperatures were recorded for the four thermocouples in the femoral head, and one each at the tip of the probe, in the probe shaft, and in the agarose 1 mm from the medial side of the femoral head. Post-thaw, the femoral head was cut open and the actual locations of the thermocouples measured for verification.

The finite element model reflected the geometry of probe used for the experimental testing, and was driven from the time-temperature curve recorded at the tip thermocouple during each benchtop test. Both non-homogeneous conductive effects and phase change latent head nonlinearity were included. Temperature curves for nodes corresponding to the location of the thermocouples were extracted and compared to the experimental temperature curves.

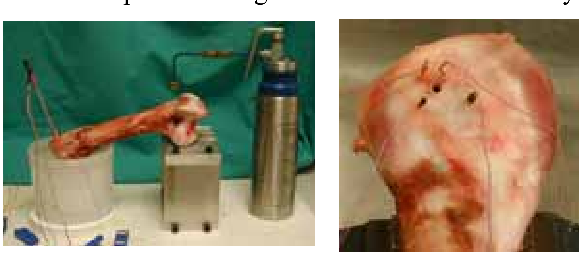

Figure 1: (a) Experimental set-up with femur in agarose and probe and thermocouples inserted into femoral head from lateral side of femur. (b) Close-up of thermocouple insertion.

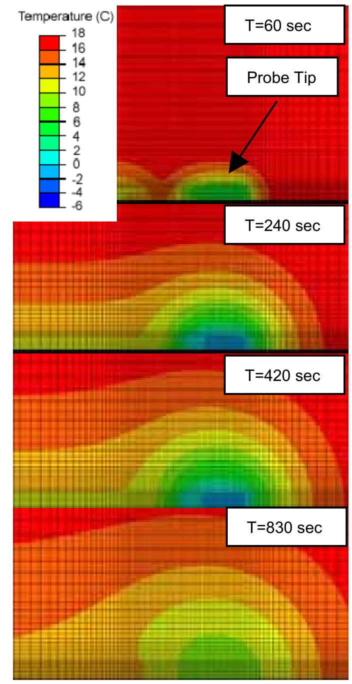

Figure 2: Finite element run of a seven-minute freeze followed by a seven minute thaw.

RESULTS AND DISCUSSION

The current FEA parameter set results in a model that is capable of replicating experimentally measured temperatures to within 3˚C (Figure 3). Because of the accurate results obtained from the testing in this preparation, the finite element model is suitable to model the freeze cycles occurring intraoperatively, with due accommodation of tissue heating effects.

CONCLUSIONS

The finite element model of cryoinsults to a cadaver emu femoral head accurately models in vitro thermal behavior.

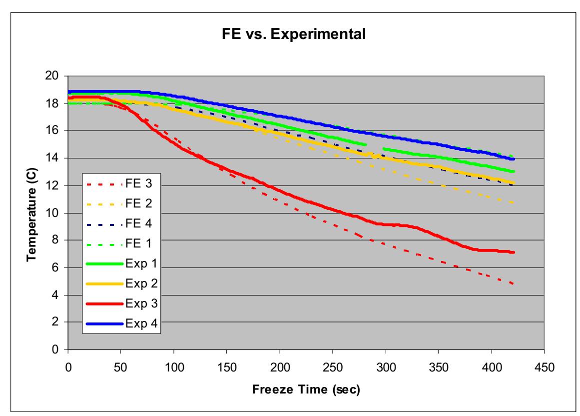

Figure 3: Temperature curves for thermocouples in the femoral head during a 7-minute freeze (thick lines) and the corresponding nodal temperature curves.

REFERENCES

1. Conzemius M, et al. *J Orthp Res* **20,** 303-309, 2002.
2. Reed KL, et al. *J Biomech* **36**, 1317-1326, 2003.

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