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Thermal conductivity of human tibia in cryoprobe freezing

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Introduction: Minimally invasive surgery utilizing ablative freezing of tissue with cryoprobes is becoming more commonplace in orthopaedic oncologic surgery for the treatment of various benign and malignant bony lesions. This technique is useful in improving outcomes while minimizing morbidity. The thermal conductivity, the intrinsic property of a materials resistance to thermal changes, of human bone is not well described in current literature. Bone is susceptible to necrosis at temperatures around 0° Celsius, considerably higher than the -40° to -60° Celsius required to cause necrosis in many tumors.[1] As such, it is important to categorize the intrinsic resistance to freezing in human bone in order to assist in surgical planning aimed at preserving as much quality bone as possible. Currently, few studies have been performed in this area and most have been investigations into the properties of animal bone.

Methods: A 2.4mm, argon-circulating cryoprobe was inserted proximally to distally into cadaveric human tibia and thermometers were placed at 0mm, 0.5mm, 1mm, and 1.5mm (Figure 1). Freezing was initiated and maintained for 10 minutes and steady state conditions were obtained before measurements were recorded. Known inputs were then combined with calculated outputs to empirically determine the thermal conductivity of human bone.

Results: The freezing profile of this probe created an ellipsoid shape as expected. The temperature profile measured -91°C, -20°C, 2°C and 12°C at each thermometer respectively. Manipulating Fournier's Law (Figure 2), with a known cooling capacity of about 0.928 W, we were able to derive that the bone in this study had a thermal conductivity of about 0.519±0.026 W/m-K.

Conclusion: Our experiment shows that bone is highly resistant to temperature changes in a freezing system. This value is consistent with studies performed in bovine bone specimens that showed a thermal conductivity of 0.53±0.030 W/mK in the circumferential direction. [2] With a susceptibility to freezing necrosis at less extreme temperatures relative to other tissues of interest, it is important to quantify thermal conductivity of bone. However, to create a patient specific planning model, additional studies should be performed to categorize the thermal resistance of bone relative to other variables such as density and location.

References:

1 Gage, A.A., Baust J.M., Baust J.G., (2009). Experimental cryosurgery investigations in vivo, Cryobiology, 59, pp. 229-243.

2 Davidson, Sean R.H. et al., (2000) Measurement of thermal conductivity of bovine cortical bone, Medical Engineering and Physics, 22(10), pp. 741 - 747

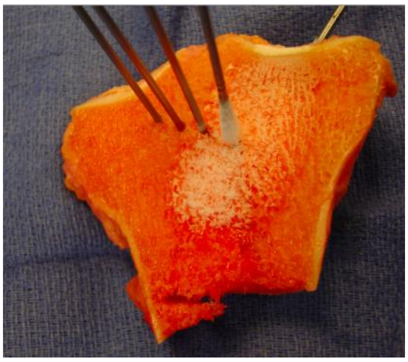

Figure 1. *Image of 2.4mm Crypoprobe inserted approximately 5cm from proximal to distal in huma tibia. The thermometers shown are placed at 0mm, 0.5mm, 1.0mm, and 1.5mm perpendicular to the axis of the cryoprobe.*

$$\dot{Q} = -kA\left(\frac{dT}{dx}\right)$$

Figure 2. Fourier's Law. Q = heat flux (W), k = thermal conductivity (W/m-K), A = area (m2), T = temperature (K), x = distance (m)