Abstract Number #11381 - Thermal Conductivity Of Human Bone In Cryoprobe Freezing As Related To Density

Thermal Conductivity of Human Bone in Cryoprobe Freezing As Related to Density

Kyle Walker M.D. [1], Todd Baldini MSc. [2], Bennie Lindeque M.D., Ph.D.[2]

[1] The Cleveland Clinic Foundation, Department of Orthopaedics
[2] University of Colorado – Denver, Department of Orthopaedics

Introduction
Minimally invasive surgery utilizing ablative freezing of tissue with cryoprobes is becoming more commonplace in orthopaedic oncologic surgery for the treatment of various bony lesions. This technique is useful in improving outcomes while minimizing morbidity. Unfortunately, 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] Thermal conductivity is the intrinsic property describing a materials resistance to temperature flow. As such, it is important to categorize the intrinsic resistance to freezing in human bone in order to preserve as much quality bone as possible. Currently, few studies have been performed in this area. Most have been investigations into the properties of animal bone. At this time, it appears no studies have been performed to quantify thermal conductivity of bone as it relates to other measurable intrinsic values such as density.

Purpose: The purpose of this study was two-fold. First, the study was designed to further establish human bone's resistivity to thermal flow. Secondly, because density is more easily determined preoperatively or intraoperatively the study was meant to investigate if there was any correlational relationship between the density and thermal conductivity in bone.

Methods
Two knees joints were obtained from a single cadaveric specimen. Each tibia and femur were cut in half in the coronal plane to make a total of 8 epiphyseal specimens. A 2.4mm, argon-circulating cryoprobe with a built in thermometer was inserted proximally to distally in relation to the joint and six thermistors were placed at 2mm increments perpendicularly from the probe. Half of the samples contained all thermistors on a single side of the probe. (Figure 1a) The other half contained thermistors alternating sides with increasing distance away from the probe (Figure 1b). Freezing was initiated and maintained for 10 minutes to achieve steady state conditions. Known inputs were then combined with calculated outputs to empirically determine the thermal conductivity of human bone. Each measured sample was sectioned to the region observed. Mass and volume measurements were taken to determine average density of each individual sample. The shaft from 2 samples was preserved for cortical bone measurements. A probe was placed intramedullary and cryoprobes were placed at measured distances away from the probe. The freezing and weight measurements were repeated as above for the epiphyseal samples.

Results
The freezing profile of the probe was ellipsoid shape as expected for this probe. Additionally, bone showed high resistance to freezing. Manipulating Fournier's Law, with a known cooling capacity of about 0.928 W, we were able to calculate the thermal conductivity of each sample using each measurement as an individual data point. Density of each sample was also calculated using mass and volume. The density of cancellous bone ranged from 0.86-1.38 gm/mL and the average thermal conductivity varied across samples but ranged between 0.54-1.18 W/m-K. Comparatively, cortical bone had a density of 1.70 gm/mL and a thermal conductivity of 0.066 +/- 0.0019 W/m-K. Average density versus average thermal conductivity for each sample is plotted in Figured 2b. The resulting data illustrated a linear correlation trend line with an R^2-value of 0.66 (p-value = 0.007).

Conclusion

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Our experiment shows that bone is highly resistant to temperature flow. This value is consistent with studies performed in bovine bone specimens that showed a thermal conductivity of 0.53±0.030 W/mK.[2] Density appears to inversely correlate with thermal conductivity. Variations in cancellous thermal conductivity were illustrated not only from one side to another but also within an individual sample. This suggests that cancellous bone has low homogeneity. Cortical bone had the lowest conductivity, lowest intra-sample variation, and highest density. For comparison, cancellous bone conducitivity was on par with that of common brick (0.6-1.0 W/m-K) while corticol bone thermal conducitivy was similar to that of cork (0.07 W/m-K).

This study was limited by the use of a single cadaver and the human error associated with placing thermistors at small increments. These increments, however, were necessary to detect temperature changes in such temperature resistive materials. We attempted to limit these errors by analyzing the average of multiple data points within a single sample. Regardless, there does appear to a strong correlation between density and thermal conductivity. Due to the variations in cancellous bone, however, any attempt to perverse bone would be likely best achieved by intraoperative monitoring of temperatures near the margins of the lesion being treated.

Figures:

Figure 1: A) illustrates samples of bone with thermistors at 2mm increments away from the probe all ipsalateral in side to one another. B) Illustrates samples with thermistors at 2mm increments alternating on contralateral sides to one another.

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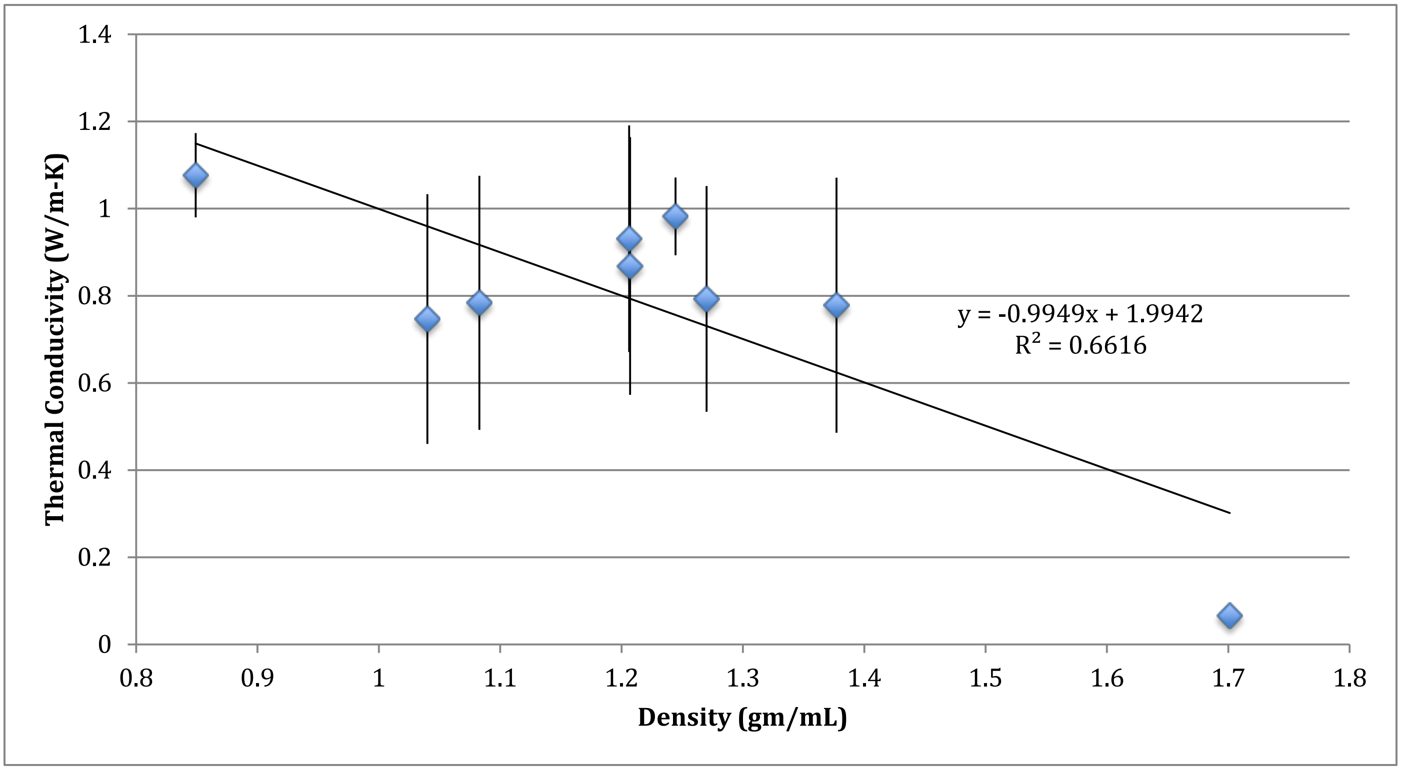

Figure 2: Plot of calculated sample density versus thermal conductivity. A trend line shows a strong linear correlation to density (p-value=0.007). A high thermal conductivity equates to a lower resistance to temperature flow.

References:

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