EMISSIVITY OF BONE

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INTRODUCTION

Treatment of long bone fractures in Orthopaedics often requires the insertion of intramedullary rods into the bones to stabilize the fractures fragments. Insertion of these rods may require reaming of the intramedullary canal to allow for proper fit and maximum stability. One potential complication of reaming the intramedullary canal is that significant heat can be generated by frictional forces. If the heat is too great, damage or death (necrosis) of the bone and possibly of the surrounding tissues can occur. Case reports have shown heat-induced segmental necrosis after reaming intramedullary canals [1, 2]. Eriksson et al have shown in a rabbit model that temperatures in bone as low as 47°C can cause bone damage [3]. Temperatures as high as 51.6°C have been measured *in vivo* by drilling holes and inserting thermocouples into the tibia during intramedullary reaming [4].

Because of the potential for bone necrosis due to heat generation during reaming it is desirable to have a minimally-invasive method for measuring the temperature of bone during surgery. Existing methods for measuring the temperature of bone *in vivo* are highly invasive and require additional holes to be drilled into the bone to allow the insertion of thermocouples. A non-contact, minimally invasive technique for measuring bone temperature during surgery could be used to reduce the risk of thermal damage during reaming. One available non-contact technique is an infrared thermometer, which is routinely used to measure skin and tympanic membrane temperatures. Accurate measurement of temperature using infrared techniques requires knowledge of the emisivity, the amount of infrared radiation emitted by a surface compared to an ideal radiator. Emissivity values for bone could not be found in the literature. The purpose of this study was to determine the emissivity of human cortical bone to allow accurate use of an infrared thermometer for measuring the temperature of bone.

METHODS

The emissivity of bone was determined according to ASTM standards (E1933-99a, Measuring and Compensating for Emissivity Using Infrared Imaging Radiometers, Non-contact Method). Five human cortical bone specimens were obtained. Specimens A, B, and C were harvested from the midshaft of the tibia from 3 different fresh frozen cadavers of unknown sex and age. Specimen D came from the midshaft of the femur and specimen E came from the midshaft of the fibula, both from the same cadaver as specimen C. All soft tissue was removed from the bone specimens.

The first test consisted of the five specimens being individually placed into an oven and heated to 37, 47, or 60°C, (according to the aforementioned ASTM standards). The temperature was maintained within ±0.2°C for 60 minutes as monitored by a type K thermocouple (Cole-Parmer, Vernon Hills, IL),. After temperature stabilization, an infrared temperature gun with a variable emissivity setting, a Raynger MX4+ High Performance Non-contact Infrared Thermometer (Raytek, Santa Cruz, CA) accurate to ±1°C, was used to measure the emissivity by varying the emissivity setting until the temperature of the gun matched the thermocouple on the surface of the bone. Temperature readings were obtained through a ½" hole in the back of the oven 12" from the specimen. The emissivity of bone was then calculated by taking the average of all the emissivity readings acquired. Two factor ANOVA with replication was run on Microsoft Excel (Microsoft Corp., Seattle, WA) to determine if there were statistically significant differences in the emissivity of the different bone specimens, the different temperatures, or an interaction between bone sample and temperature. Significance level was set at $p<0.05$.

The second emissivity test was performed to determine the sensitivity of the temperature reading to the emissivity setting. To establish this relationship, four of the specimens, (A, B, C, and Femur) were placed in the oven as in the first test, and heated to both 37°C and 47°C. The emissivity setting was varied from 1.07 to 0.97 in 0.02 increments and a temperature recorded at each increment. The data was then processed to find an overall, usable relationship between emissivity and temperature.

2003 Summer Bioengineering Conference, June 25-29, Sonesta Beach Resort in Key Biscayne, Florida

The previous two tests utilized dried bone samples. The third test was to measure the emissivity of fully hydrated bone in order to more accurately simulate *in vivo* bone. Specimen B was soaked overnight in a water bath to hydrate it. The B specimen was partially submerged in a water-bath in the oven and tested at 40.5°C and the emissivity was determined the same way as in test 1.

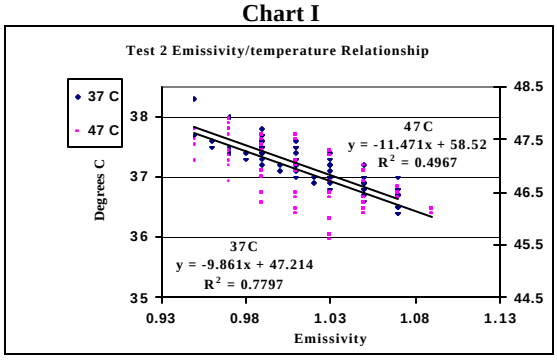
RESULTS

The average emissivity of bone was 1.01 +/- 0.034 with a range between 0.94 and 1.06 (Table I). Two factor ANOVA indicated that there was a significant difference between the emissivity of the 5 bones tested ($p<0.001$) and between the emissivity at the 3 temperatures tested ($p<0.001$). Additionally, the interaction term between bone sample and temperature was significant ($p<0.001$). The second test showed that the change in temperature per 0.01 change in emissivity was 0.1 C° for 37°C, and 47°C (Chart I). The third test showed that the average emissivity of wet bone to be 1.04 at 40.5 C°.

Table I

Specimen	37° C mean (Std. Dev.)	47° C mean (Std. Dev.)	60° C mean (Std. Dev.)
A	1.04 (0.004)	1.01 (0.010)	0.99 (0.010)
B	1.01 (0.004)	0.98 (0.010)	1.05 (0.010)
C	1.05 (0.005)	0.99 (0.000)	0.98 (0.000)
D	1.03 (0.005)	0.99 (0.000)	1.00 (0.005)
E	1.00 (0.005)	0.94 (0.010)	1.06 (0.006)

Chart I



DISCUSSION

The average emissivity of cadaveric bone was determined to be 1.01 making temperature measurements of bone with a non-contact infrared thermometer possible. This is close to the emissivity of skin, which is reported as 0.98 [5]. With the significant differences between emissivity value and both bone specimens and temperatures there will be errors in the temperature measurements. However, for every 0.01 the emissivity varies from the true value there is only an error of 0.1 C°. This is an error of 1.2 C° over the range of emissivities measured. This small error in temperature would not be clinically relevant.

There were several limitations to this study, which should be noted. The bones used were of unknown origin and both and age and gender may influence the emissivity of bone due to changes in mineral and organic content. Also, there were only 5 specimens tested, though the results were statistically significant. Finally, these tests were done on cadaveric tissue and the results may differ for live tissue. Further *in vivo* testing will be performed to validate these results.

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