CHAPTER **52**

# POTENTIAL FOR THERMAL INJURY DURING SURGICAL OSTEOTOMY

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## ABSTRACT

Medical literature indicates that permanent tissue damage to bone can occur when exposed to temperature elevations of as little as 5°C for times as short as a few seconds. Clinically, it has also been observed that during surgical osteotomies significant amounts of heat are typically generated. We present experimental data that suggests critical conditions for thermal injury are regularly exceeded during simulated surgical procedures using cadaveric metatarsal bones.

## INTRODUCTION

Inherent in the mechanical cutting of any material is heat generation through friction. This temperature increase can have adverse effects on the ability of the bone to heal itself. Microscopic evaluation of bone during and after heat application has shown that thermal necrosis can occur when bone is exposed to critical temperatures.[1] Bonfield and Li concluded that temperatures of 50°C and over are associated with irreversible changes in the structural and physical properties of bone.[2] Prior to this finding, the critical temperature was thought to be 56°C.[4,6] Bearing in mind that the normal human body temperature is 37°C, this small change could be a very common occurrence during osteotomy. Eriksson's vital-microscopic study in the rabbit has shown that bone regeneration may be significantly impaired when bone is exposed to a temperature of 47°C for one minute. This finding shows that thermal damage to bone is the combined result of the temperature and the period of time that the bone tissue is at the elevated temperature.[3] The effect of high amounts of heat on the bone for even a short period of time can result in the denaturation of the enzymatic and membrane proteins; bone cells will be resorbed and replaced by fat cells.[5] Yet at a temperature of 44°C for one minute, no significantly adverse effect on the initial bone was observed.[4]

Osteotomies are very common surgical procedures performed on thousands of patients daily throughout the world. As such, determining the mechanical conditions under which excessive heat is generated can help to develop surgical procedures and protocols to lessen or even eliminate the occurrence of thermal injury.

## EXPERIMENT

An experimental apparatus and procedure were developed to investigate heat generation coupled with force levels during simulated surgery. The design incorporated a three-point load beam to record force measurements (Figure 1) as well as thermocouples to record temperature changes during the cut. Cadaveric bones were used in order to preserve human bone properties and morphology (Figure 2); these were supplied by the Podiatry Institute (Tucker, Georgia). The bones were cut using a standard surgical Chevron cut (Figure 3) using a sagittal reciprocating saw. Digital data acquisition was used for recording temperature and force data and plotted using PC based statistical software.

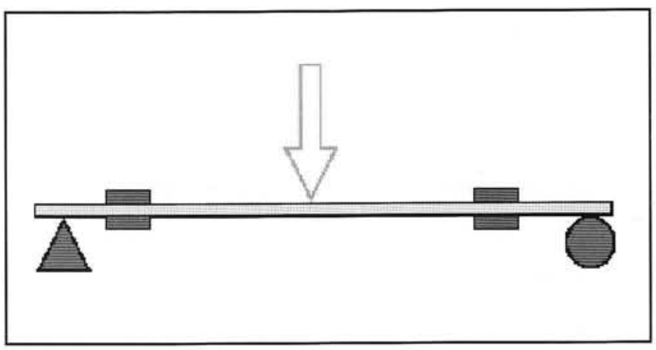

Figure 1 – A photograph providing an overview of the experimental apparatus and the bone-cutting procedure. An instrumented cadaveric bone is mounted on balance beam and is cut by a podiatric surgeon using a pneumatically-driven surgical bone saw. The procedure is intended to simulate a typical bunion surgery. Bone temperature histories at various locations are recorded using an array of thermocouples; surface temperature measurements at the cut site have also been attempted using an infrared thermometer. Further details on the experimental components are found in Figures XX-XX.

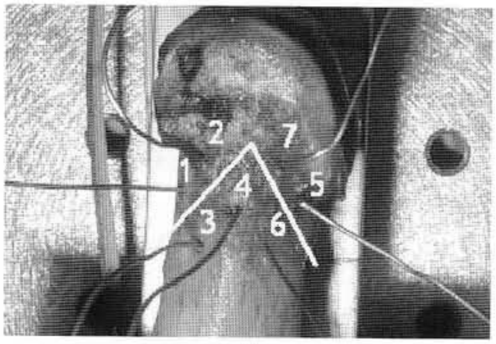


Figure 2A. Photographs of the instrumented cadaveric specimen. (a) The bone is mechanically stabilized by mounting it in a block containing a fast-curing fiber resin (Bond-O™). The block is in turn mounted to 3-point supported beam instrumented with strain gages for force measurements.

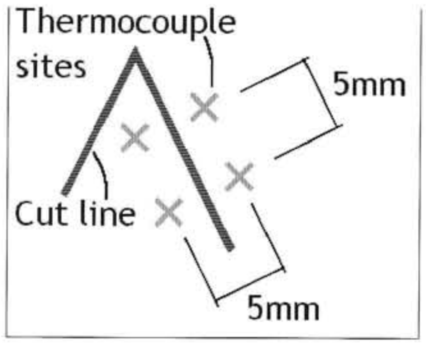


Figure 2B. (b) Close-up on the instrumented bone showing the thermocouple placement. The wedge-shape line indicates the intended path of the cut. Thermocouples are nominally placed at a distance of 2.5 mm from the cut and are separated from each other by a distance of 5 mm.

### Temperature Measurements:

The temperature measurements were performed using K-type chromel-alumel thermocouples with a sheath diameter, d = 0.508 mm (.020"), temperature measuring range of –270 to 1372°C, approximate sensitivity of 0.039 mV/°C, and accuracy of ±0.2°C. This type of thermocouple was chosen because it is reasonably corrosion resistant and a relatively linear output could be assumed. The thermocouples were calibrated using an ice bath, T = 0°C, as the "cold" reference junction. The relative voltage due to the temperature rise at the thermocouple's hot junction, a bath of a known temperature, was amplified and recorded on a voltmeter.[13]

An array of seven thermocouples was chosen to monitor a sufficient area at a high enough frequency to yield reliable data. The array was press fit in the bone to a depth of 0.5mm (figure 3) in order to keep the thermocouple junction inside the cortical bone where the significant heat is generated. The thermocouple array was arranged to have the temperature at each leg of a cut measured by four thermocouples. Cuts were made using a Hall® sagittal saw supplied by Fletcher Allen Health Care of Burlington, Vermont.

### Force Measurements:

Force measurements were performed with CAE-XX-250-UW general-purpose strain gages. The gages were constructed of constantan encapsulated in a protective polyimide coating. The beam was constructed of 6061-T6 aluminum with a pin fulcrum at one end and a roller on the second end to ensure pure bending.

The beam was instrumented with an array of four strain gages (one top and one bottom at each end of the beam in pairs) and attached to a P-3500 gage box.[14] The strain gages were arranged in a Wheatstone bridge

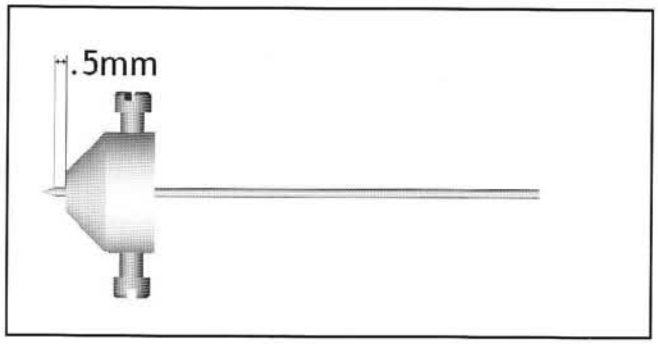


Figure 3 – A CAD rendering of the drill-stop designed to allow for the precise depth placement of 0.5 mm. The drill-stop is essentially a precision collar constructed to fit a Linvatec® surgical K-wire driver.

configuration for maximum resolution and repeatability. This configuration allows the same reading for a force applied at any point between the sets of strain gages. The beam was calibrated by applying known loads First metatarsals were chosen and mounted in a fiber-filled resin block, which was secured to the beam for the duration of the cut.

### Data Acquisition:

A NI 4350 National Instruments Data acquisition board was used to acquire voltage outputs from the arrays of thermocouples and strain gages. The output from the DAQ system was read through LabView 6 PC based software in 8 channels of data (7 thermocouple, 1 strain gage. The channels were read in series (channel 1, then 2, and so on) at a .85 Hz sample rate per channel.

Along with the thermocouple and force data, an infrared thermometer was used to measure surface temperature at the osteotomy sight (Figure 5).

**Procedure:**

The bones were stored in a –70°C deep freeze and allowed to come to room temperature before mounting and cutting. Bondo® was used as the mounting medium because of its reliability and low heat generation during curing (a high heat generation may damage the tissue before cutting begins).

Each bone yielded two cuts, one Chevron cut on each the medial and lateral sides. It was assumed that the heat generated through cutting of the medullary bone was not significant in relation to the cortical bone. The location of the cuts and thermocouples were marked on each side of the bone with pencil to aid in keeping a set distance between the heat generation and thermocouples. The midline of the bone was also marked to give a stopping point for each cut. Thermocouples were located in a 5mm square on each side of the wedge (Figures 3 & 6). The thermocouple (#4) located at the apex of the cut was common to the two cuts.

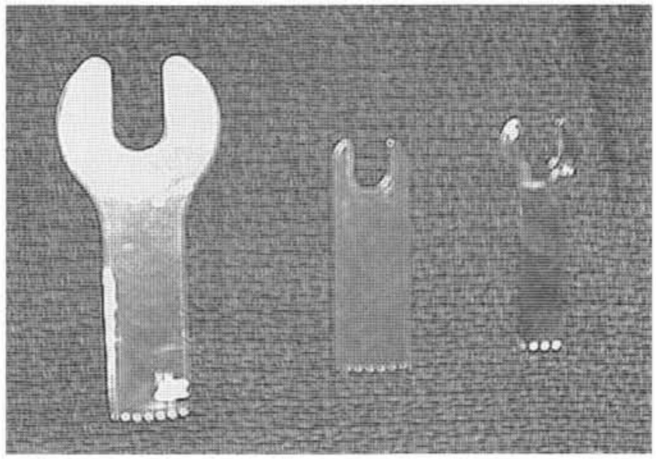

Figure 4- Photograph of the sagittal saw blade used in the experiments. It is a Linvatec Micro Series with a blade thickness of 0.4 mm. The teeth configuration is ???.

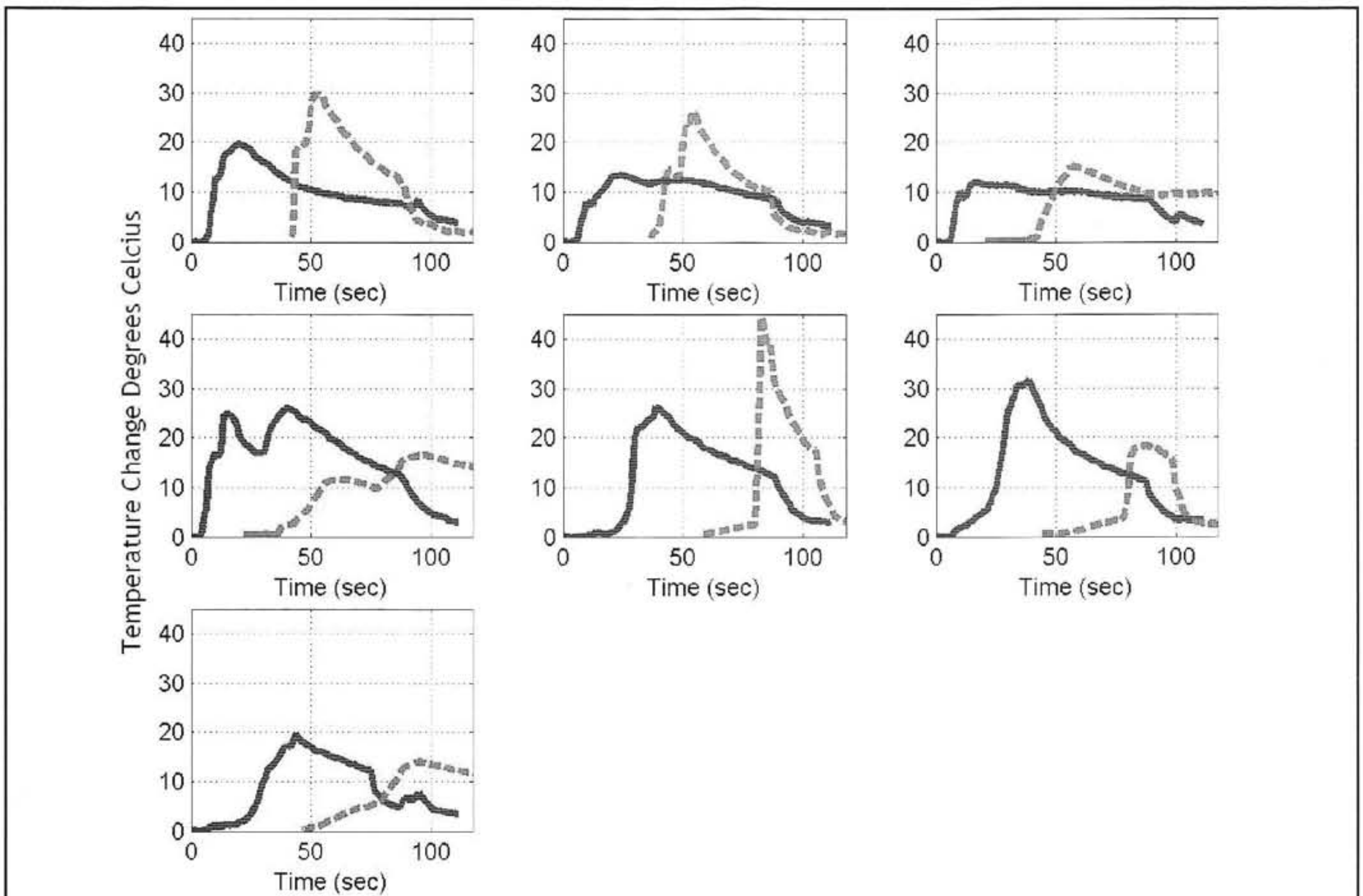


Figure 5. Temperature elevation (DT) histories recorded by the thermocouple array during a simulated bunion surgery on a cadaveric metatarsal bone with healthy cortical and medullar bone. Each plot represents the history at a given thermocouple location, as referenced in Figure 2b, and contains data for two sets of cuts. The solid lines represent plantar and dorsal cuts on the medial side of the first metatarsal, which had a total duration of approximately 110 seconds. The dashed lines represent similar cuts on the lateral side of the same bone but with a somewhat shorter duration of about 80 seconds. The placement depth of the thermocouples was 0.5 mm in all cases and the mean cortical thickness was XXXX. Significant temperature elevations seen on a wide-spread basis; for this experiment, a temperature increase spike of nearly 45 ∞C was measured.

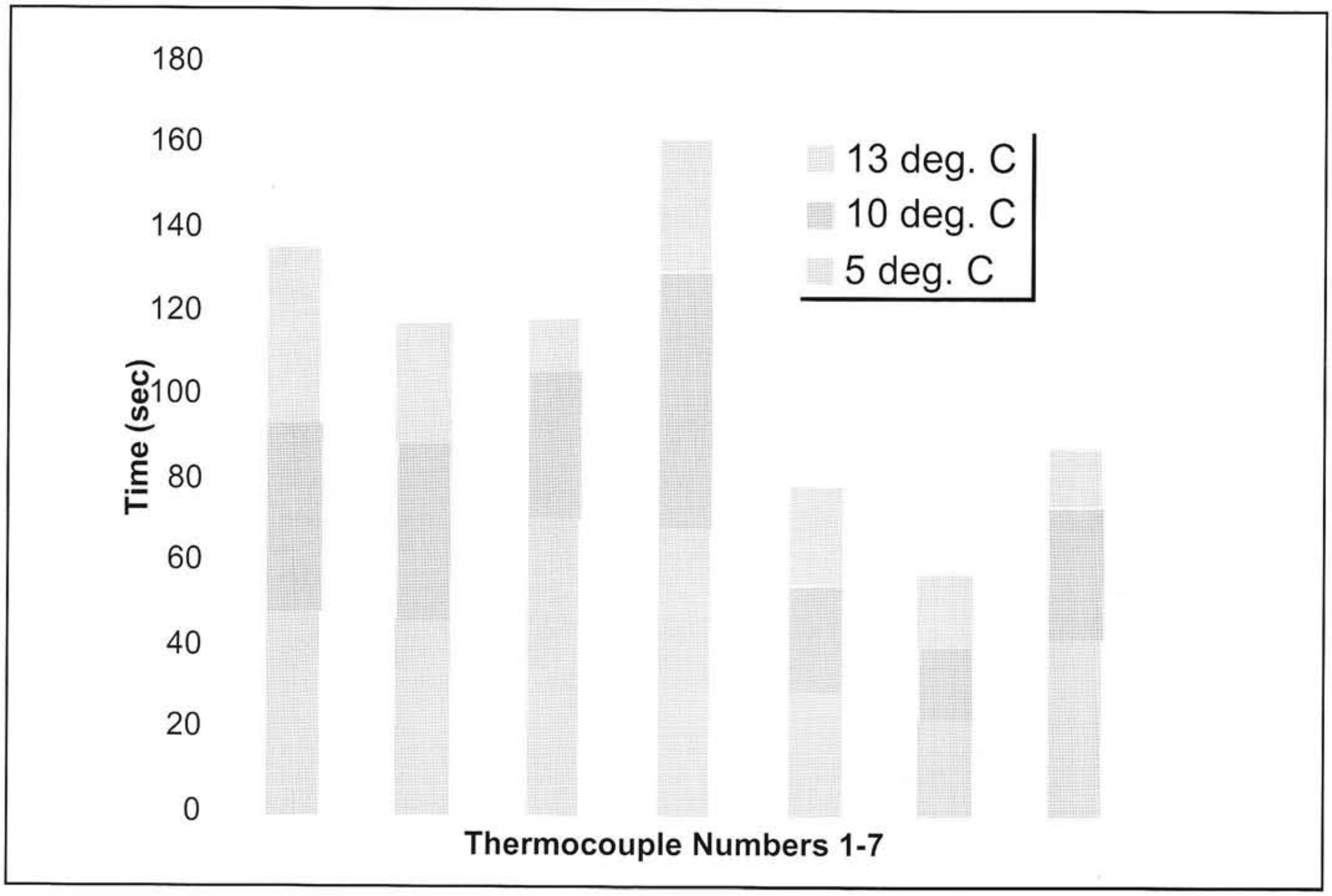


Figure 6. Time durations of critical temperature level excesses based upon the data shown in Figure 5. The critical temperatures elevations of 5, 10 and 13 degrees Celsius were previously identified in this article as being those conditions producing increasingly severe thermal injury.

At the apex of one cut, a Steinman pin was driven through the bone with an AMSCO /Hall air-driven drill to the apex of the opposing cut to guide the saw through. .018" holes were drilled to press fit the seven thermocouples and set to a depth of .5mm using a custom designed and built Drill Stop (Figure 7).

The mounted bone was then fastened to the beam with a wing nut attached to threaded studs located on each of the four sides of the mounting puck. Thermocouples were then attached to the data acquisition board.

The LabView program was tested by starting the program and immersing each of the thermocouples into a bath of known temperature; this also served to ensure the thermocouples calibration and connection.

The thermocouples were then pressed into the .018" drill holes by hand using a pair of 90° needle nose pliers.

Thermocouple leads were held in place with duct tape to keep them from pulling the tips out of the bone (Figure 8).

The strain gage box was attached to the data acquisition board via a BNC output and adjusted to maximum voltage output. A digital video camera was set up aimed at the cut site for recording of the cuts for future reference.

All data acquisition equipment was started just before the beginning of the cut. All cuts were performed by Dr. Marc P. Sarnow, a podiatrist experienced in surgical osteotomy, to increase repeatability of cutting pressure and technique.

The cut was begun on one side of the osteotomy and stopped when the cutting edge of the blade reached the midway point through the bone. The second cut was begun immediately as in clinical osteotomy. Once the second side of the wedge was cut to the midline of the bone a period of 1 minute was allowed for the bone temperatures to settle.

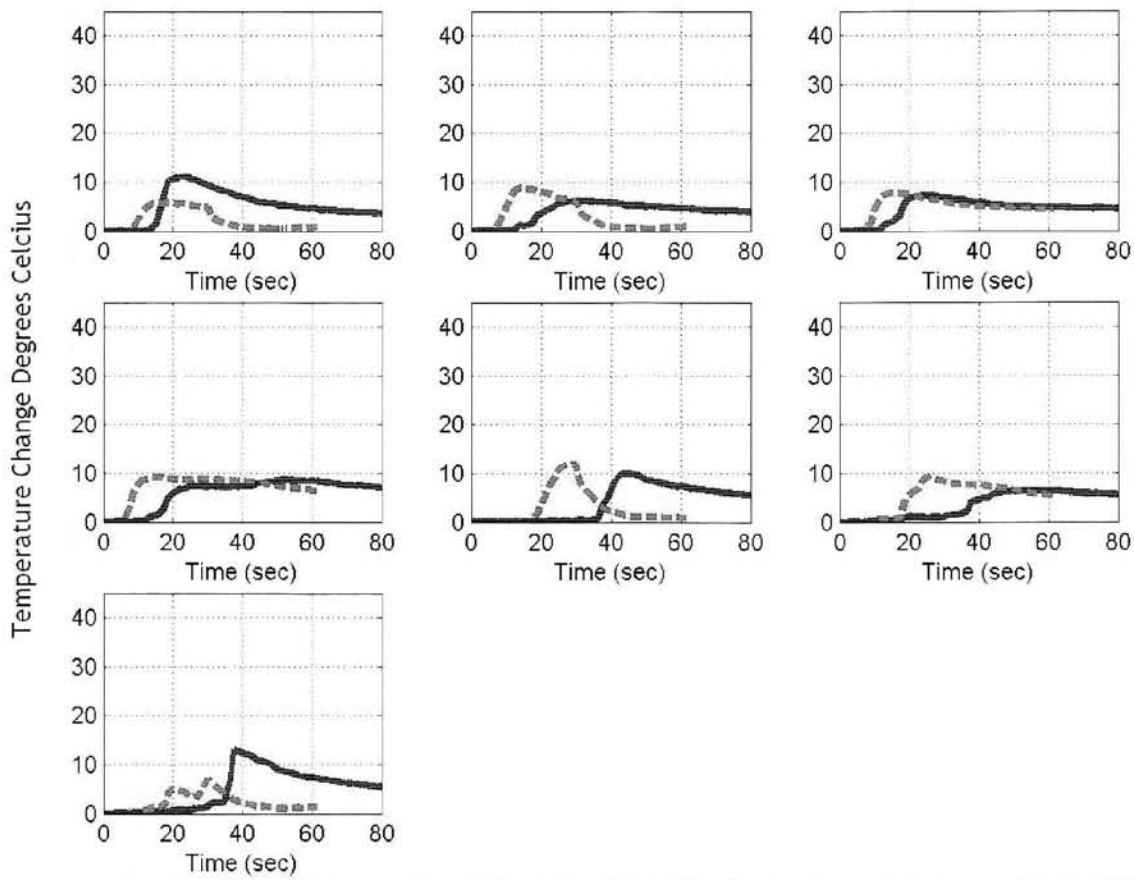


Figure 7. Temperature histories recorded by the thermocouple array during a simulated bunion surgery on an osteoporotic specimen. This specimen had a large cyst at its core and no discernable cortical bone. A comparison with the results shown in Figure 5 shows that a substantially lower amount of heat was generated for the osteoporotic bone versus normal bone. The measured cortical thicknesses for this specimen ranged from essentially ~0 to 1 mm, suggesting that cortical thickness may play a significant role in heat generation.

All data acquisition equipment was then stopped, data saved and programs reset. Thermocouples were removed from the bone and cleaned of any residue that could affect future measurements. The bone and mount were removed from the beam and inverted to cut the second side.

The second side of the bone was set up as the first with all procedures being the same for both sides.

## RESULTS

Ten data sets were recorded and analyzed. Maximum temperatures for all cuts and thermocouples are shown in Figure 8. The average maximum temperature spike for all thermocouples during the ten cuts was 12.94°C.

Sample plots of thermocouple data is shown in Figures 9 and 10.

## CONCLUSION

The results of this experiment show that critical temperatures are regularly exceeded during simulated surgical osteotomy. Temperature spikes as high as 38°C were recorded.

Temperatures at the cutting surface were not obtainable using the thermocouple method. It is thought that these temperatures are significantly higher than the thermocouple recorded temperatures. Research is being conducted to develop a model to accurately extrapolate the actual temperature at the cutting surface.

Cortical thickness is thought to be a major factor in the generation of heat. Cortical thicknesses are difficult to discern before an osteotomy is performed which presents a problem in predicting temperature spikes. Properties such as bone density could be used to help in determining heat generation when cortical thickness is not available.

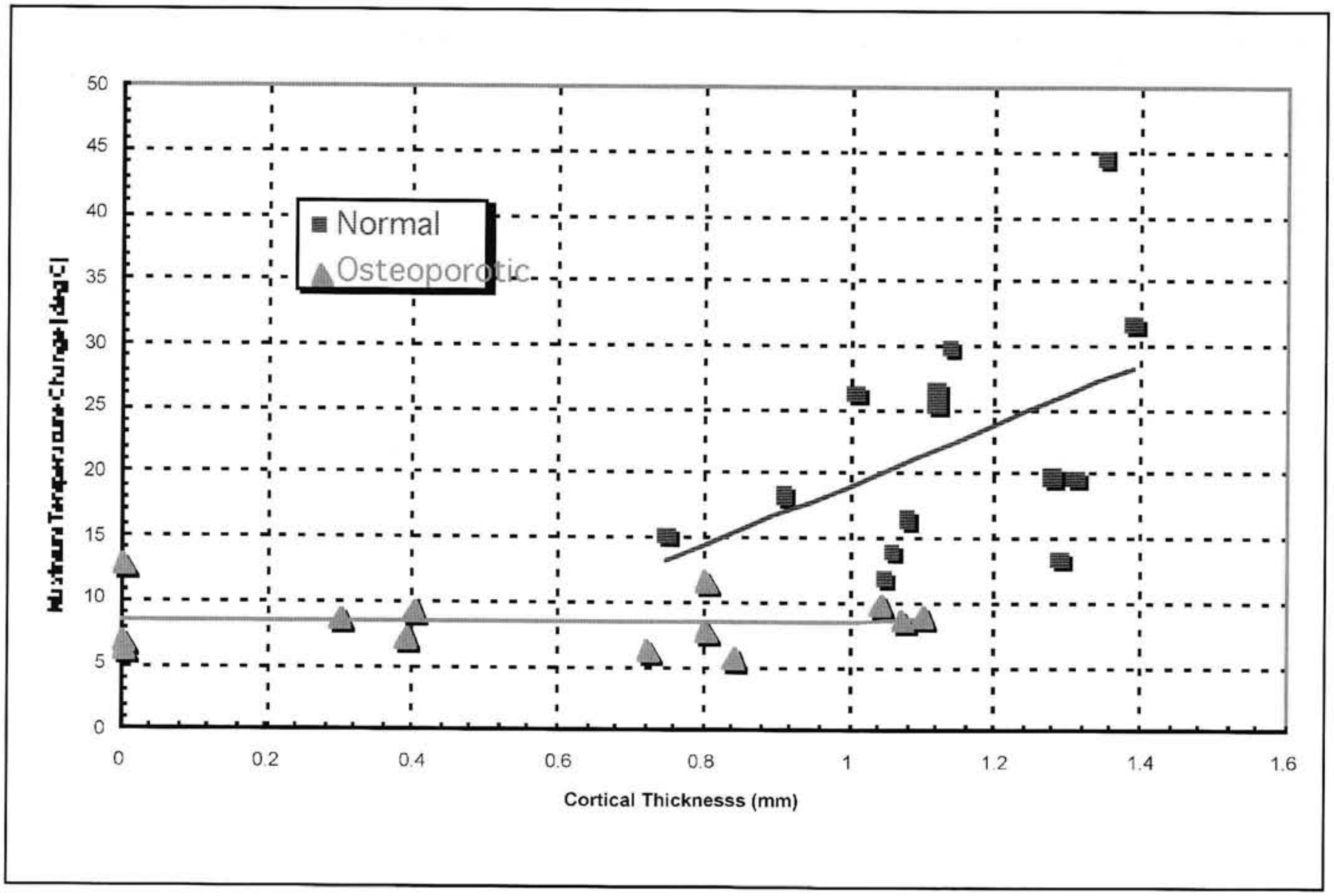


Figure 8 – A scatter plot showing the site-by-site correlation between maximum temperature increase and cortical thickness for the data sets from Figure 5 (squares) and Figure 7 (triangles). Trend lines have been drawn through the data points for illustrative purposes. A clear and distinct grouping of the two data sets is evident.

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