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Investigation of Drill Bit Temperature during Automatic Bone Drilling

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ABSTRACT

Bone drilling operations are carried out in hospitals in different surgical operations worldwide (e.g. orthopedic surgeries and fixing bone breakages). It is considered one of the most sensitive processes in biomedical engineering field. During drilling, the most critical problem is the rise in the temperature of the bone above the allowable limit. A Study showed that the allowable limit that must not be exceeded is 50°C. Moreover, if this limit is exceeded, the bone may sustain serious damage, namely, thermal necrosis (cell death in bone tissue). The research in this paper focuses on reducing the temperature rise during bone drilling. A study was conducted to observe the effect of the drill rotational speed, feed rate and drilling depth on the drill bit temperature during drilling of goat and cow bone. Experimental methods were engaged to optimise the drilling parameters in order to achieve an accepted level of drill bit temperature.

Keywords: Bone drilling, Temperature, Thermal osteonecrosis, Drill bit.

1 INTRODUCTION

Bone drilling is an important process which is frequently encountered in various medical practices. In curing bone breakage, a drill is used to make a hole through the bone that will be used for the insertion of screws for fixing fractured bone parts. This is considered aiding the broken bones to recover their original location. During the drilling operation, the temperature generated in the bone must not exceed an allowable limit. Any increase of the temperature above the allowable limit will lead to thermal osteonecrosis (cell death) [1, 2].

Thermal osteonecrosis is known as death of bone cells due to lack of blood flow. It is caused by an extreme increase in the temperature of the bone, which is led by the change of the phosphates alkaline state of the bone. Death of bone cells weakens the bone structure and decreases the material stiffness where the drilling procedure is taking place [3]. For bone breakage fixation and reconstructive surgery, weakening the bone structure will lead to the implants loosening and losing their place. Augustin et al. [4] rated the implant failure for lower leg osteo synthesis in the range of 2% - 7%. While the loosening of bone-implants can be due to several factors, the focus of this paper is on thermal osteonecrosis.

The increase in bone temperature and the amount of exposure time to the heat are the two factors that determine the damage level of the bone [4]. Much research has been conducted and the following was discovered; thermal osteonecrosis occurs if the temperature of the bone is between 47 °C - 50 °C for one minute. If the exposure time is less than or equal to one minute, thermal osteonecrosis effect can be avoided [5]. Another study showed that thermal necrosis takes place immediately if the temperature exceeds 70 °C [6]. However, it was revealed by many researchers that the cell death occurs if the temperature increases above 47 °C for more than one minute [7].

There are several parameters that have a direct effect on the increase in temperature during bone drilling, namely, rotational speed, feed rate, drilling tool diameter and drilling depth. Vaughn et al. [8] found that an increase in rotational speed leads to an increase in bone temperature. Karaca et al. [9] investigated the bone temperature variations during drilling by using a high quality thermocouple. They found that the temperature increased by decreasing the feed rate and compressive force. Moreover, the temperature increased with an increase in rotational speed.

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The variations of drill tool diameter effect on the temperature has been widely researched. Kalidindi investigated the effect of changing tool diameter on the temperature. The parameters in his setup were three different drill tool diameters of 2, 3.5 and 4.3 mm, rotational speed of 1200 rpm and feed rate of 0.42 mm/s. It was found that the temperature increased exponentially with the increase in drill bit diameter.

This paper presents a study result for measuring the drill bit temperature while varying the rotational speed, feed rate and fixing the drill bit diameter. With a purpose of understanding the effect of drilling parameters on the generation of temperature through the drilling operation.

A literature review of previous studies is presented in this paper, followed by the setup and experiment for acquiring the temperature values. Finally, validations and comparisons are conducted in relation to the literature review. This research is limited to the temperature of the drill tool only due to the poor heat conductivity of the bone. However, an increase in the drill bit temperature will cause the bone temperature to increase as well.

2 REVIEW OF RELATED WORK

For the last decade, several studies have investigated the effect of different drilling parameters on the temperature of the bone. When investigating the effect of the variations in the rotational speed, Matthews et al. investigated the bone drilling of human femur bone, they observed that there is a small change in the bone temperature while varying the rotational speed from 345 to 2900 rpm [10]. Tompson [11] stated that there was a major increase in the temperature accompanied with increasing rotational speed from 125 to 2000 rpm.

On another study made by Sharawy et al.[12] On drilling pig jaw bones, the results showed that the mean temperature increased with varying the rotational speeds from 1225 to 1667 and 2500 rpm. Hillery and Shuaib [13] presented a study where they proved the existence of a decrease in the temperature with an increase in rotational speed from 400 to 2000 rpm while using a drill bit diameter of 3.2 mm. Lee et al. [14] observed that while drilling human femur bone, the rise in temperature is due to the increase in spindle's speed and the decrease in temperature is due to the increase in feed rate.

When investigating the effect of the variations in the drill bit diameter. Hufner et al. [15] found that a small diameter and a long length drill bit tends to deviate from its location during the drilling of the bone. Another study made by Augustin et al. [16] investigating the effect of drill bit diameter on the temperature while drilling into pig bone. They observed that when the drill bit diameter increased, the contact surface area between the bone and drill tool increased, leading to an increase in the temperature of the bone.

Tahmasbi et al. [17] presented a study to show how varying the drilling parameters affects the variations in temperature during bone drilling procedures. They also developed a solution to optimize the process. Their approach was to vary the drill bit diameter from 2.5 to 4 and 5 mm. For each different drill bit diameter, the temperature measurement were taken whilist varying both feed rate and rotational speed of the drill. Figure 1 shows the outcome of their investigation for one of the three drill bit diameters due to its relevance to the drill bit diameter used in this paper.

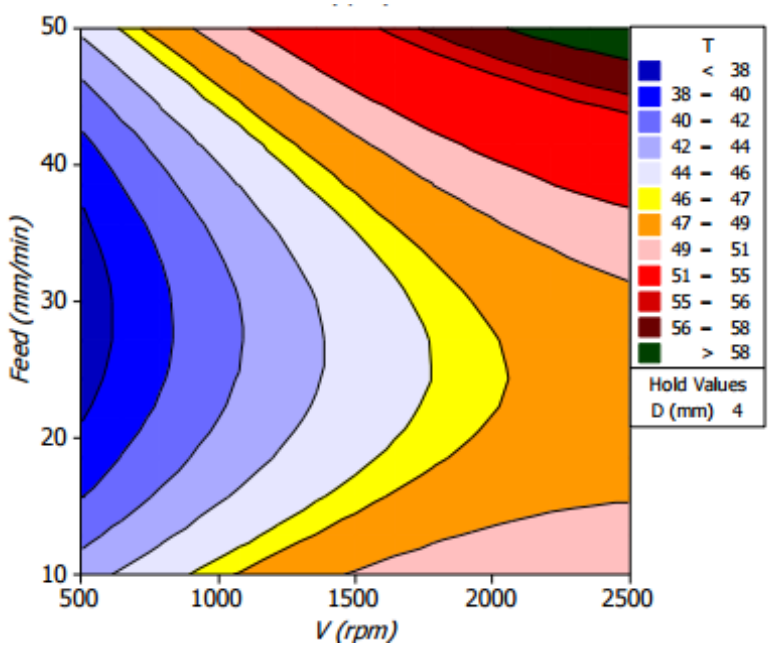

Figure 1: Temperature diagram of feed rate and rotational speed with drill bit diameter of 4 mm [17].

Due to the variety of tests that were conducted by Tahmasbi et al. [17], they were able to generate a graph that shows the effect of increasing the drill bit diameter on the temperature. Figure 2 shows the variation of tool diameter on the temperature of the bone. Where the figure indicates that with an increase in drill bit diameter, the temperature of the bone also increases. It can also be seen that with using a 5 mm drill bit diameter, the temperature of the bone increased remarkably as mentioned in the literature.

3 SETUP AND EXPERIMENT

In this section, the procedure taken in obtaining the temperature of the drill bit and the equipment used is mentioned and discussed briefly. Finally, results are discussed and compared to literature review studies. The drilling procedure was carried out by using an Automatic Smart Bone Drill that stops the drilling procedure upon breakthrough of the bone and retract to its initial position. Figure 3 shows the proposed automatic bone drill system. A K-type thermocouple was used to measure the temperature of the drill bit, a vice was used to secure the bone from any sudden movement. The thermo-couple sensor used can be seen in Figure 4, where the temperature measurement was directly taken upon the completion of the drilling procedure. This was achieved by manually using the probe depicted in Figure 4 and reading the temperature value shown on the screen.

The procedure of the drilling operation starts when the start button is pressed, the automatic drill will carry out the drilling procedure till breakthrough takes place. Following that, the drill retracts to its initial position and the thermocouple is then used to measure the temperature of the drill bit tip. Several drilling experiments were conducted on goat and cow bone to test out different bone thickness and density while varying the feed rate and rotational drilling speed. The input feed rate was varied from 2 – 10 mm/s and the drilling speed was varied in the range of 2500 to 7500 rpm with incremental intervals of 2500 rpm.

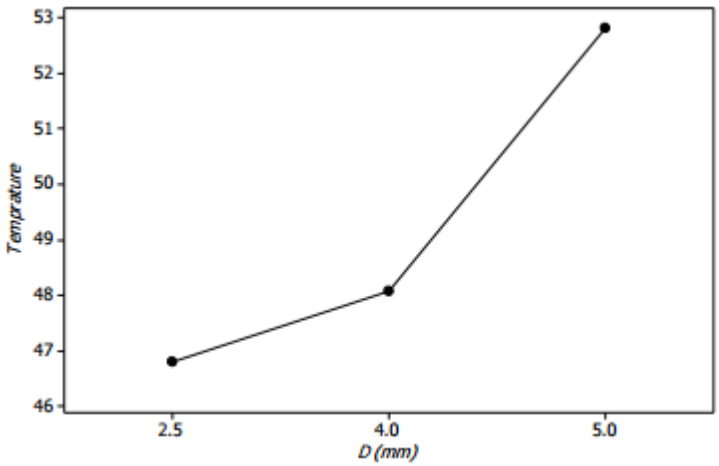

Figure 2: Effect if varying drill bit diameter on temperature.

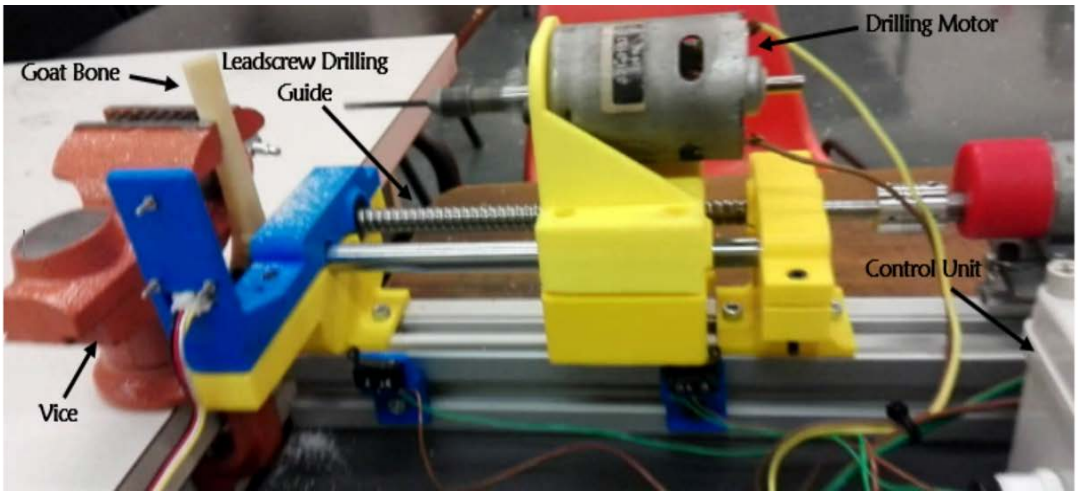

Figure 3: Smart automatic bone drill device

The bone used during the drilling procedure was cooked and fixed using a vice, those two points are considered limitations which is a scenario that will not exist in real drilling procedures. Those limitations will not allow the experiments to correlate to actual bone drilling procedures. However, it can show the principle of temperature variations due to change in drilling parameters.

The First experiment conducted involved using a goat bone of thickness of 3 mm with a feed rate of 3 mm/s and rotational speed of 2500 rpm. The drilling procedure was executed three times in order to measure the average temperature accompanying the specified drilling parameters. Table 1 shows the temperature measurements for experiment one. The results obtained shows a small variation in the three tests. However, this can be due to the thermocouple used and the room temperature.

Experiment two involved use of three different bone thickness in order to understand the effect of the drilling parameters on the temperature. The feed rate used was 3 mm/s with a rotational speed of 2500 rpm. Table 2 shows the temperature measurements for experiment 2. The results shown in Table 2 highlights that with an increase in the bone thickness, there is a clear increase in the temperature of the drill bit. Moreover, the temperature measured when drilling into cow bone was shown to be high. This implies that the temperature of the bone itself is exceptionally high, which can show that for the used drilling parameters and bone thickness of 5.8 mm onwards, the probability of thermal osteonecrosis occurring is high.

In experiment three, a cow bone of thickness 7.5 mm was used, the rotational speed was varied from 2500 to 7500 rpm with incremental intervals of 2500 rpm, while fixing the feed rate at 3 mm/s. The drilling procedure was carried out and the temperature of the drill bit tip were recorded. Table 1 shows the values of the measured temperature for this experiment. Figure 5 shows the effect of increasing the drilling speed on the temperature of the drill bit tip while fixing the feed rate. Figure 5 shows the increase of temperature value due to an increase in rotational speed. This statement was investigated in literature and reflected upon in this experiment. The rise in temperature is partially due to increasing the thickness of the bone specimen, extending the drilling time and thus increasing the temperature.

Experiment four involved fixing the drilling speed at 2000 rpm and increasing the feed rate from 3 to 10 mm/s with incremental increase of 3 mm/s. the bone used was goat bone with thickness of 3 mm. Upon the execution of the three drilling procedures, it was noticed that the drilling device stalled during the drilling procedure when using a feed rate of 10 mm/s, leading to an extremely high measured temperature above 70 °C. A temperature that high for the drill bit means an even higher temperature in the bone, and at these circumstances thermal osteonecrosis cannot be avoided. Therefore, an increase in feed rate while keeping the rotational speed fixed at a low value can lead to high elevation in temperature. Figure 6 shows the outcome of experiment four.

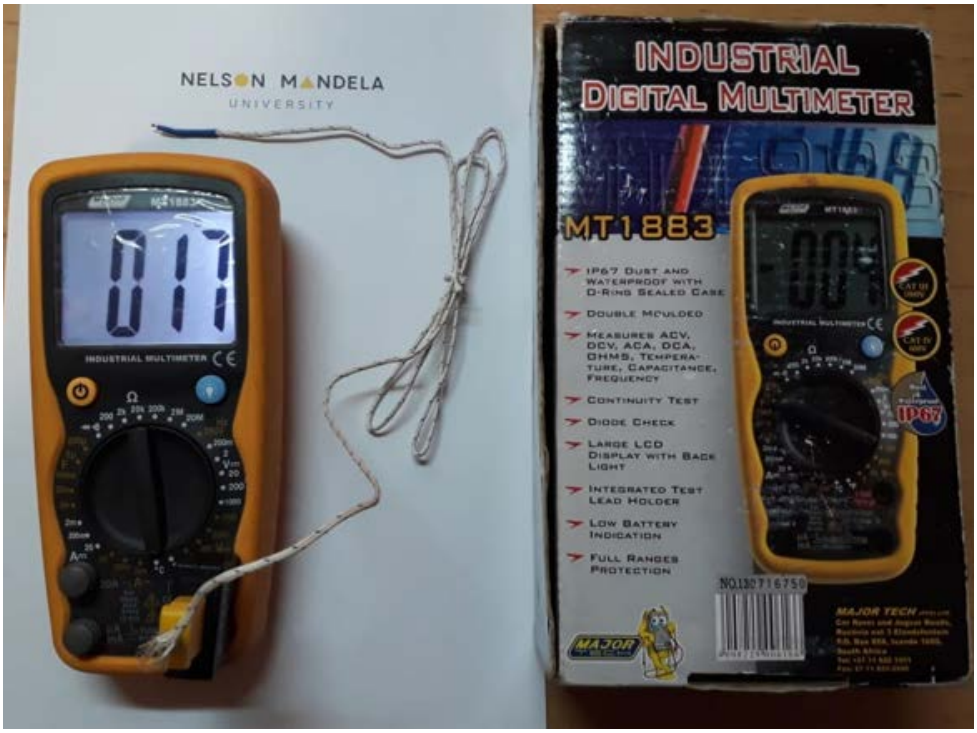

Figure 4: Thermocouple sensor arrangement

Table 1: Temperature measurements for experiment 1

Tests	Temperature °C
Test 1	28
Test 2	29
Test 3	28.5

Table 2: Temperature measurements for experiment 2

Bone Type	Thickness (mm)	Temperature °C
Goat	3	28
Goat	3.5	31
Cow	5.86	40

Figure 5: Effect of rotational speed on the temperature.

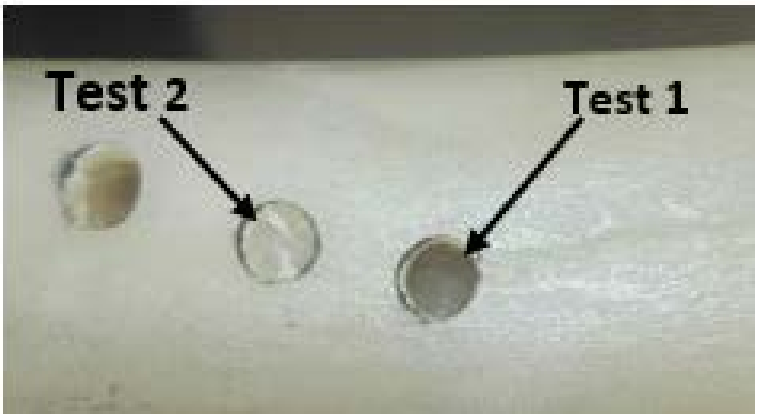

Figure 6: Effect of increasing feed rate and fixing rotational speed at 2000 rpm

4 CONCLUSIONS

In this study testing the effective drilling parameters on the temperature of the drill bit was presented using a thermocouple and a developed smart automatic drilling device. Previous research was mentioned in the literature reviewed in order to draw a guideline and a common understanding of the effect of high temperatures on the bone. This study showed:

- The temperature increases as the thickness of the bone increases. A speed of 2500 rpm and feed rate of 3 mm/s while drilling into goat bone of 3 mm thickness has proved to yield the least generated temperature. This confirmed what was mentioned in the literature reviewed.
- Improving the measurement method is necessary in future work in order to measure the bone temperature accurately, to meet the real requirement for bone drilling operations and to achieve the optimal technique for bone drilling while adhering to the safety rules.

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