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Drill Bit Design and Its Effect on Temperature Distribution and Osteonecrosis During Implant Site Preparation: An Experimental Approach

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Abstract. In this study, the drilling parameters will be evaluated to obtain optimal parameters in minimizing the impact of drilling damage on synthetic bone blocks. The effect of damage observed in the study is osteonecrosis that occurs in the drill hole for implant site preparation, where a smaller value is desired. The drilling parameters are optimized using the Taguchi method with two control factors: the feed rate and spindle speed; each parameter is designed in five levels. This experiment was then carried out on four different designs of drill bits, i.e., Twist (118°and 135°), spherical, and conical drill bits. While experimental planning uses L25 orthogonal arrays, the "smaller is better" approach is used as a standard analysis. The main findings of this research are 118° point angle twist drill bit is the ideal type of drill bit for bone drilling, as it produces less heat than other types of drill bits. The optimal range of feed rate and drilling speed for bone drilling is 40-60 mm/rev and 1000-1400 RPM, respectively. Combining these parameters helps to minimize heat generation during implant site preparation drilling.

1. Introduction

Orthopedic surgery often involves drilling into bone to insert implants like screws and plates or to create a pathway for screws. However, the friction created during this process can produce high temperatures, potentially resulting in thermal osteonecrosis, i.e., cell death caused by heat. This can compromise the success of the surgery and cause complications post-operatively [1, 2]. The design of the drill bit plays a crucial role in determining the amount of heat produced. Hence, understanding the relationship between drill bit design and heat production is vital to improve surgical outcomes.

The effect of various drill bit designs has been examined, specifically twist, spherical, and conical, on heat generation during bone drilling, given their significance in orthopedic surgical procedures. Twist drill bits contribute notably to heat elevation due to their helical cutting-edge geometry which generates friction against bone tissue, potentially leading to thermal osteonecrosis [3, 4]. Spherical drill bits, on the other hand, result in lower heat elevation due to their round cutting edges, which reduce the surface contact area with the bone [5, 6]. This reduced heat production can potentially minimize the risk of thermal osteonecrosis, thus enhancing surgical outcomes. Conical drill bits have been shown to lead to substantial heat elevation because of the increased friction caused by their wider cutting surface at the base [6]. Similar to the effect of twist bits, the heat generated by conical bits can risk causing thermal osteonecrosis, posing

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a threat to the success of surgical procedures [7]. Understanding these thermal effects is critical for improving surgical techniques and preventing bone damage during orthopedic operations [8].

The aim of this study is to investigate the influence of different drill bit designs on heat generation during the drilling process into synthetic bone blocks. Synthetic bone blocks, chosen for their similar density and composition to human cortical bone, offer a reliable and ethical platform for initial investigations before clinical trials.

2. Materials and Methodology

Three types of orthopedic drill bit designs, with different cutting geometries - twist, spherical, and conical, were employed in this study shown in Figure 1. The synthetic bone blocks used were made of hydroxyapatite, simulating the hardness and mineral content of human cortical bone.

Figure 1: Types of drill bit (a) 118° Twist drill bit, (b) 135° Twist drill bit, (c) Spherical drill bit, (d) Conical drill bit, and (e) Synthetic bone blocks.

For the experiment, a hole is drilled to insert a thermocouple (a device to measure temperature) referred to as predrilling. The predrilled hole has a diameter of 1mm and a depth of 8mm to match the subsequent drilling depth. This ensures that the thermocouple can accurately measure the heat generated during the drilling process. Figure 2 illustrates the positioning of the thermocouple hole relative to the drilling hole, and the midpoint values are used to calculate distances between the holes on the bones. The setup utilizes only one thermocouple, placed at a consistent distance from the drill bit's point to measure the heat increase during the entire synthetic bone drilling process.

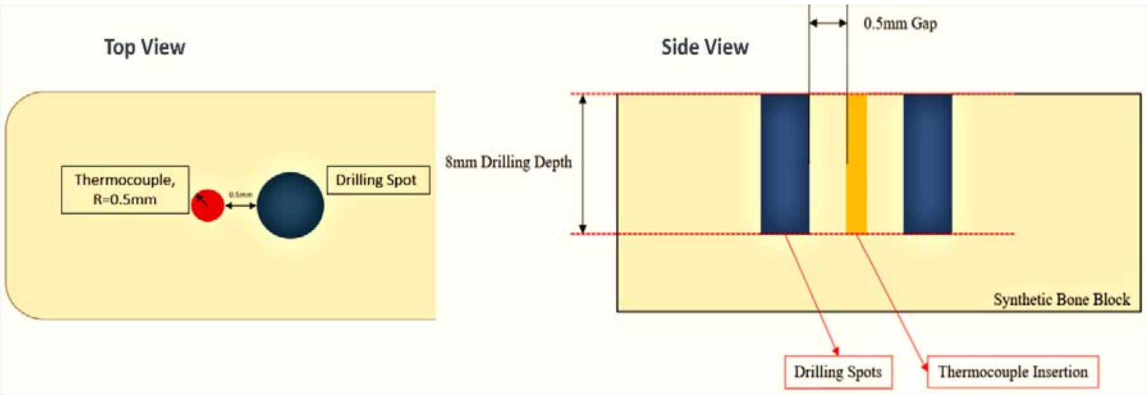

Figure 2: Synthetic bone drilling plan design.

A CNC machine will serve as the platform for synthetic bone drilling in this project. Initially, the synthetic bone block will be securely clamped to a bench vice, which will then be affixed to the bed of the CNC machine. In Figure 3, the experiment commences with a 2mm drill bit featuring a 118° point angle, set to a fixed drilling depth of 8mm. Various combinations of drilling speeds and feed rates are employed, as outlined in Figure 3. To ensure consistent results, the ambient temperature is carefully controlled at 22-23 °C by turning on the air conditioner. Moreover, plastic foams are utilized to seal any gaps in the lab's doors and windows, preventing external heat from influencing the results. The initial temperature of both the drill bit and synthetic bone block is of utmost importance for result consistency. Therefore, the FLIR E6 thermal imaging camera is employed to monitor their surface temperature. The experiment can only commence once both the drill bit and synthetic bone block have sufficiently cooled down. The heat elevation data will be recorded and saved to a thermocouple thermometer. Irrigation, a type of coolant that effectively removes chips and other debris, is typically used to prevent flute clogging when drilling into bone. However, this research will be carried out without using irrigation, in order to study the influence of heat generation without irrigation during bone drilling.

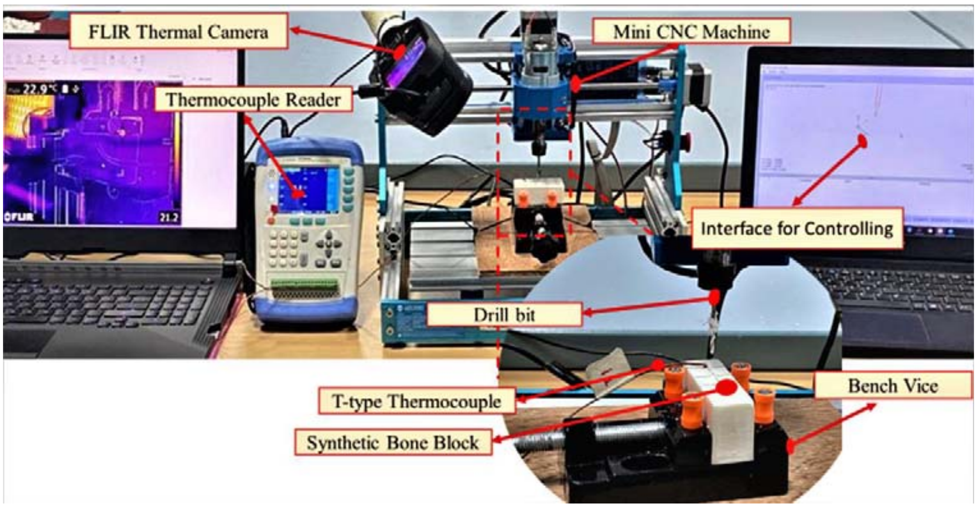

Figure 3: Apparatus setup for synthetic bone drilling process

The drilling process was carried out under controlled conditions to keep the environmental parameters, such as ambient temperature and humidity, constant. An infrared thermographic camera was used to record real-time temperature rise during the drilling process.

3. Results and Discussions

All drill bit designs exhibited a temperature increase during the drilling process, albeit to varying extents. However, differences in the magnitude and distribution of heat generated were observed across the four designs. The graph showing the effects of the control factors obtained with the Taguchi Method (Figure 4) on the changes in temperature mean confirms the results obtained from the experimental studies. The optimal conditions are marked in the Figure 4.

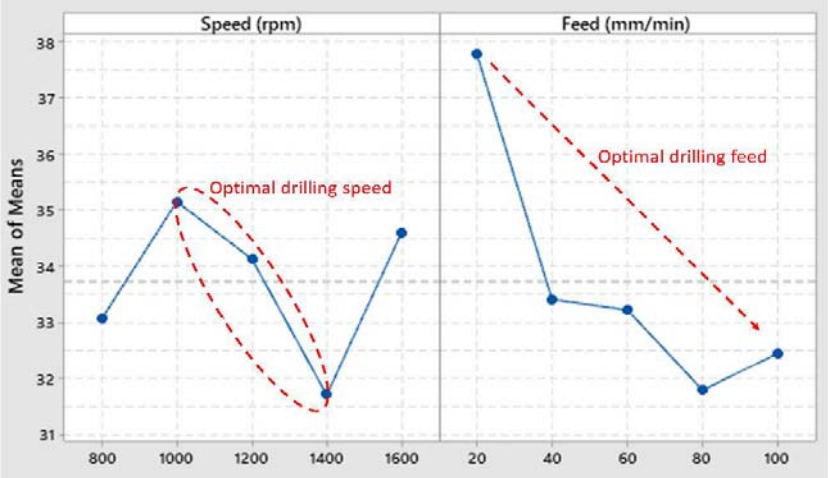

Figure 4: Effect of process parameters on average temperature mean.

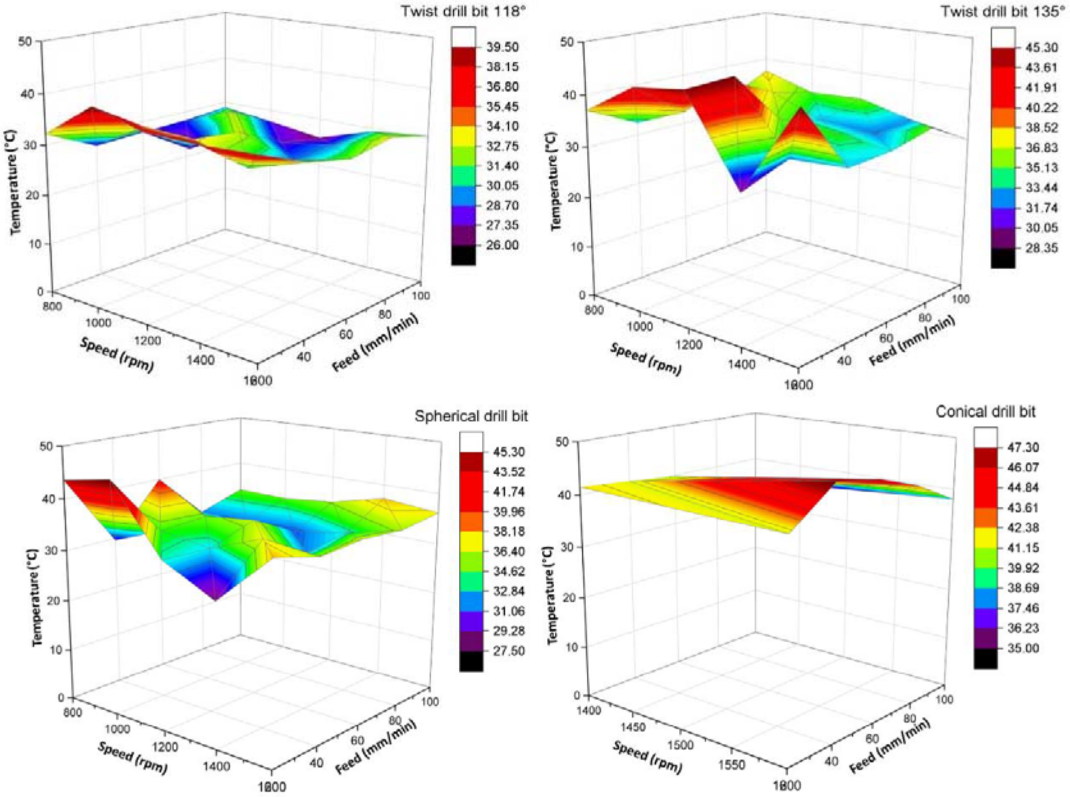

Figure 5: Effect of the cutting parameters on Temperature.

Twist 118° drill bit is associated with the lowest rise in temperature, followed by spherical and then twist 135° and conical drill bits. The changes in the temperature are obtained as a result of the experimental study are shown in Figure 5. Depending on the difference in the drilling tool, there was not much change in the temperature values. However, a possible explanation for the superior performance of twist drill bit could be their enhanced cutting efficiency and effective chip removal. Efficient chip removal may reduce the friction between the drill bit and the synthetic bone block, which in turn, decreases the heat produced.

4. Conclusion

Our study highlights the impact of drill bit design on heat generation during the drilling of synthetic bone blocks. It provides crucial insights into the design modifications that can potentially improve surgical outcomes by minimizing the risk of thermal osteonecrosis.

- Among the 4 types of drill bits used in this research (point angle 118° twist drill bit, 135° twist drill bit, spherical drill bit, and conical drill bit), it is experimentally proven that the point angle 118° twist drill bit is the most suitable drill bit type in bone drilling as its small point angle produces lower drilling forces and required much less torque per unit area of hole and energy, per unit volume of bone drilled at a given feed rate. Its sharp drill end will cut more easily and produce less heat.
- In this experiment, five different feed rates are tested for synthetic bone drilling: 20, 40, 60, 80, and 100 mm/rev. It was found that the optimum feed rate, which produced the best results, was between 40 and 60 mm/rev.
- Five different drilling speeds are tested for synthetic bone drilling, namely 800, 1000, 1200, 1400, and 1600 RPM. It is concluded that the optimum drilling speed, which produced the best results, was between 1000 and 1400 RPM. This was the case when the preset feed rates were used.
- These findings contribute valuable insights to orthopedic surgeons and researchers, aiding in the development of more efficient and safer bone drilling practices. Understanding how drill bit geometries influence heat generation in bone drilling can lead to improved surgical techniques, ensuring enhanced long-term outcomes and durability of implanted joints. Further investigations are required to validate these findings in a clinical context, contributing to safer and more effective orthopedic procedures.

Acknowledgments

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