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EFFECT OF TEMPERATURE ON BOVINE BONE MACHINING BY VARIATION OF THE CUTTING TOOL ANGLE

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Abstract

Bones are made up of living cells that have the capacity for adequate blood supply and renewal. But bone cells face the risk of being permanently harmed when exposed to high temperatures. The blood flow to the area could be harmed by overheating, leading to bone infraction. The term "heat osteoporosis" refers to this condition, and bone drilling is a crucial surgical technique for orthopedic surgeons. Heat is produced during drilling as a result of friction between the bone and drilling tool interface; this results in the death of regenerating tissues and long-lasting repair. Prior researchers mainly focused on fracture fixation techniques using a variety of orthopaedic implants, different drilling types, drill geometry, and applied load, such as Kirschner wires, intramedullary nails, plates and screws, etc. In this study, three different types of implant sites—proximal, mid, and distal diaphysis—with two different cutting angles on a sample of bovine bone are studied when holes for implants are fixed. The drilling at a cutting angle of 90^0 is seen to be a more relevant parameter.

Keywords : Bone drilling, surgical drilling, conventional drilling, cutting tool angle, heat development

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1. Introduction

According to Hillery et al. [1], the intercellular calcified material that makes up bone is a special type of connective tissue. Drilling bone is a critical component of several procedures, including orthopaedics and neurology. Heat can quickly accumulate at the drilling site, increasing the risk of thermal osteonecrosis, because the bone has relatively weak thermal conduction and a particular capacity for heat (Bohra et al., [2]). Cutting experiments revealed that the suggested blade design considerably reduced clogging, enabling stable and low force of cutting to be maintained. Wang and co. [3] the most reliable approach for examining the thermal characteristics of bone drilling is experimental research. The experiment is often conducted in one of two ways: either using thermocouples or with infrared thermography. According to Jamil et al. [4], the surgeons' main goal while drilling into bone is to create accurate holes without injuring the surrounding tissues physically or thermally. They also arrange all the study's parameters, performance metrics, logical comparisons, and constraints. A heated vascular necrosis condition in the bones can occasionally arise as a result of a combination of poor drilling process parameters. Varatharajan et al. [5] demonstrate anticipated thrust force and torque in mechanistic models and verified their findings using robot-assisted surgical drilling before drawing their conclusions. Shihao and colleagues [6]. Early research indicated that the applied force and torque produced during bone drilling increased in size as the feeding rate rose. by Huan et al. [7]. The cutting model in question, which accounts for shearing pressures, edge pushes, and forces brought on by tool wear, yields the best results. To increase the level of safety throughout the surgery, the AI can provide the surgeon with more information regarding the position of the bits in the bone in light of this [8]. According to Lin et al. [11], incorporating the cutting force into the chip forming force while taking the immediate depth of cut for bone drilling results in significantly lower process force and heating due to varied chip deformation and decreased chip thickness [9]. Spindle speed had the greatest impact on surface roughness, whereas cutting depths had the most visible impact on cutting force. Additionally, cutting force and a decrease in cutting temperature take place when coolant is added Zhang et al. [12], and similar studies According to Gherkin et al., samples of rib were drilled continually and sporadically in order to compare the results of the exterior watering approach with those of both interior and external double irrigation operations. [13], Drilling parameters were changed to maintain a strong thrust force while reducing damages. Previous investigations, such as Sinan et al. [14], spoke Real-time measurements of the heat output were made with the use of thermocouples and infrared thermographs. With two drill holes and a focus on drill wear, ten trials were carried out by Henrich et al. [15, 16]. A universal tool wear monitoring model is difficult to create, according to Luo et al. [17], and predicted cutting force is comprehensively established by accounting for the wide variety of entry and departure angles for each engaged cutting edge. A model for simulating the cutting area and cutting forces was developed [18,19], which decreased the coefficients of friction (COF) of the drilling fluid [20] and increased machining precision and tool life. Model prediction for cutting force For the forecast of temperature elevation, cutting-edge technologies were employed. Only a few research have been done, according to Agarwal et al. [21–24], on the computation of discretized nodes along the cutting edges of hobs. The regional major cutting directions were examined by Azvar et al. [25]. We primarily focused on the bovine tibia bone with various cutting angles on the surface of the various implants in this in-vitro study.

2. Materials and Methodology

Bone drilling is a common medical practice. Numerous surgically created holes have been detected during the early assessment. Recent years have seen the start of bone drilling studies with the use of modern technology. It will serve as an example of the ideal circumstances for bone machining in particular. The resources and technique will be shown in the section below. A few criteria for this analysis were picked based on this research's pilot study.

2.1 *Specimen Details*

The most crucial stage of the current research approach is choosing study specimens during the drilling process. No animals were hurt during the selection of the specimen for this investigation; instead, a fresh, 450 gramme cow tibia bone that was taken from the butchery house was used. The animal was 4 years old, which is the same age as a young adult (30 years old) with the right mechanical and thermal characteristics. Before machining began, the endosteum was removed.

2.2 *Tooling Information*

Another key element of the machining of bone is choosing the appropriate tool for the drilling. The hollow design of the instrument, according to earlier studies, decreases the temperature and modifies the shape of the bone chips, but this study refutes those claims. The results of the pilot research and an extensive review of the literature were used to choose the autonomous drilling variables. To choose four different drill bit types with diameter ranges of 2 mm, 3 mm, 3.5 mm, and 4 mm, the best nomenclature for the helix, point angles, and tool lip was selected. For machining to achieve good bio-compatibility and wear and tear, HSS is the preferred material tool.

2.3 *Process Parameters and Experimental Design*

Bone sawing is a required step in orthopaedic surgical procedures such as osteotomies, arthroplasty, and amputations. Low temperature and great cutting surface quality are essential because they lessen thermal damage and improve surgical recovery. The intercellular fibrils and osteons that make up the anisotropic structure of bone thus far [1] are its main constituents. The results of the pilot research [22,23,24] and the literature review have been used to choose the major input process parameters that have the biggest impact on drilling. Three important process factors were picked and changed up to five levels, as indicated in Table.1. There has been extensive research on low-speed drilling at 300 rpm. Therefore, the same criteria used for traditional drilling, including low spindle speed (RPM) of 600–800 rpm, depth of cut (DOC) of 12–18 mm, and drill diameter of 2–4 mm, are also used for this structure. Studies on the cutting angle with temperature evaluation were few in number and were being conducted less often. The three implant locations in the material for this study are in the mid, distal, and proximal diaphyses of the bovine bone, as per the clinician's advice. For a better in vitro study experience and results, we conducted some preparatory drilling. In order to achieve better results, procedure parameters can be adjusted and arranged in different potential combinations with a thermocouple placed close to the implant site. It is calibrated and has good accuracy values. The chosen process parameters are shown in Fig. 1.

Table 1: Process Parameters for Machining of various levels

Input Parameters	Abbreviation	Units	Ranges
Spindle Speed	RPM	rpm	600-800
Depth of Cut	DOC	mm	12-18
Drill Diameter	DD	mm	2-4

2.4 *Experimentation and Drilling Process*

To begin drilling, the defrosted bone is picked out and fastened to the drilling work table. At 280C, room temperature, all of the experiments are conducted. At least two holes were received for each speed and depth. When drilling quickly into bovine cortical bone, the drill bit occasionally became jammed because the chips didn't clear along the hole. However, in this technique, bovine tibia bone was chosen and machined at various RPMs, including 600, 650, 700, 750, and 800. For each speed with various combinations of the previously discussed additional parameters. Cutting angle, one of the most crucial process variables, was adjusted for each combination while taking note of the temperature during machining. The machining time is also mentioned; these major elements were used for graphical display of the results. For better outcomes, a K-type thermocouple was employed with an LED display as shown in Fig. 1.

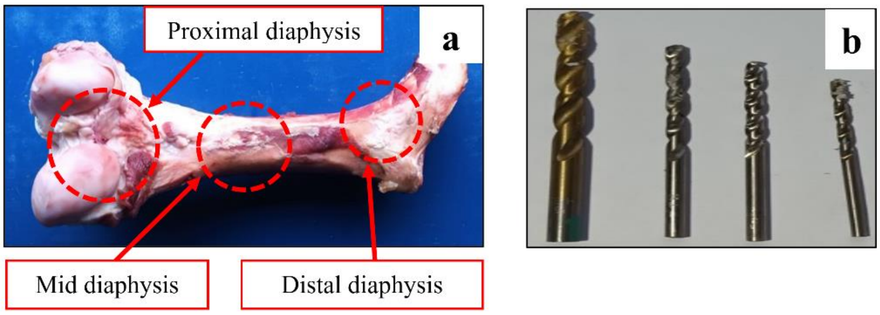

Fig. 1. (a) Bovine Bone (b) Drill bit variation from Ø2 mm to Ø4 mm

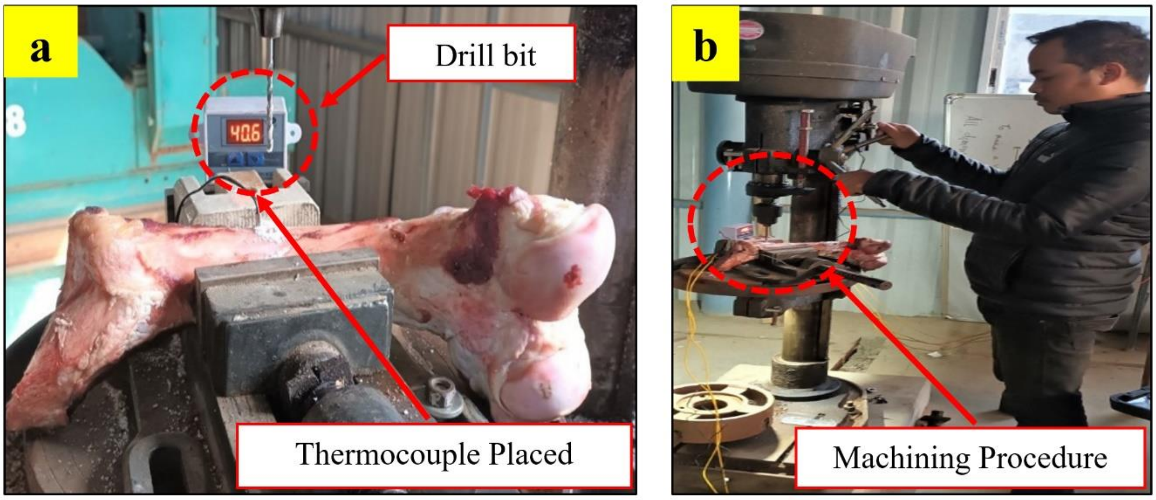

Fig.2. (a) Experimental Setup, (b) Machining Process

The selected rotational speed and cut depth were varied in different combinations to determine temperature. These combinations show which elements work best together to address the perfect drilling operation parameters and the precise drill geometry. Aside from that, when the bone was being machined, the temperature was examined in relation to the metalworking parameter combinations, the depth of the cut for the bone, and the machining time. Additionally, the temperature was noted for both low and high values for optical parameters, with the findings and graphical representations shown below.

3. Results and discussion

The drilling process was carried out using several drill bits, and the temperature variations that took place while the implant site was being prepared were observed. The Bovin bone has produced the following results when drilled using the trivial bone axis at 450 and 900 cutting angles. The cutting angle was not taken into consideration [25] when choosing the process parameters for the study [22,23,24], which caused a rise in temperature with conventional drilling [1,2,3]. As a result, it has been observed through the use of the pilot study that temperatures will rise during both conventional and rotary ultrasonic bone drilling.

3.1 *Speed vs Temperature*

With the increased drilling speed, the large temperature changes have been observed while drilling the bovine bone. Figures 3, 4, and 5 depict variations in temperature at the proximal, mid, and distal diaphyses of the tibia bone, respectively, along with the corresponding spindle speed. The 30 second machining time is chosen. In all three locations of the bovine bone, proximal, mid, and distal diaphysis, it was shown that the temperature of the bone rose as spindle speed increased.

The following information is noted for the 45^0 cutting angle. The maximum temperature of the bovine bone increased by 61% at the proximal region at the 600 rpm spindle speed, followed by 58% and 42% at the distal diaphysis and mid region of the bovine bone, respectively. As speed increases, temperature likewise rises dramatically. The proximal portion of the bovine bone reached its highest temperature at 800 rpm, followed by the mid and distal diaphysis regions at 73% and 72%, respectively.

The following information is noted for the 90^0 cutting angle. The maximum temperature of the bovine bone increased at the 600 rpm spindle speed at the proximal region by 56%, followed by the distal diaphysis and mid region of the bovine bone by 51% and 40%, respectively. With increasing speed, temperature rose significantly. The proximal area of the bovine bone saw the highest temperature at 800 revolutions per minute (72%), followed by the mid and distal diaphyses with 70% and 60%, respectively.

Based on the results of spindle speed on temperature having transitory rises in the temperature with 45^0 higher over 90^0 cutting angles on the proximal region, the mid-diaphysis temperature was increased with the spindle speed with unique depths as we discussed process parameters. As was the case with the proximal and mid diaphyses, which were both significantly increased in this implant position with a rise of 45^0 over 90^0, the mid diaphysis region demonstrated optimal results with the mild temperature rise.

In order to reduce the likelihood of osteonecrosis, the implant site was treated as a standard region based on the link between temperature and machining time. Based on the findings of spindle speed on temperature having transient rises in the temperature with 45^0 higher over 90^0 cutting angles on the proximal area, the mid-diaphysis temperature was raised with the spindle speed at distinct depths. It was discovered that an angle of 90^0 over 45^0 led to the best temperature decline in the proximal region.

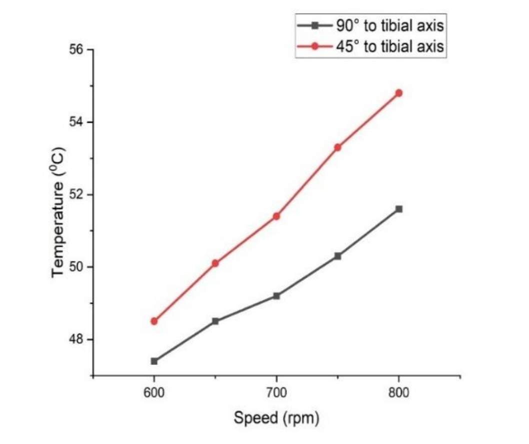

Fig.3. Variation in temperature when drill bit at the Proximal region of the tibia bone

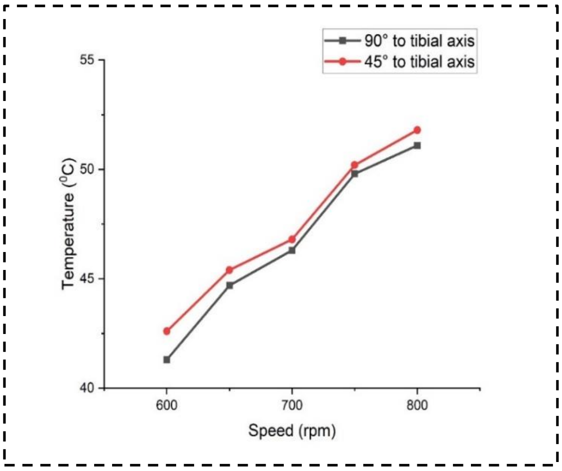

Fig.4. Variation in temperature when drill bit at Mid region of the tibia bone

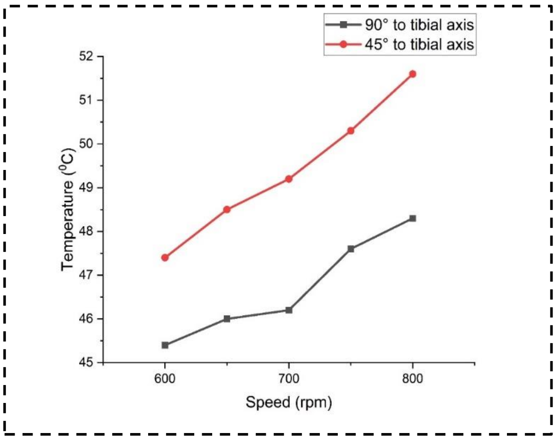

Fig.5. Variation in temperature when drill bit at the Distal region of the tibia bone.

3.2 ***Machining Time Vs Temperature***

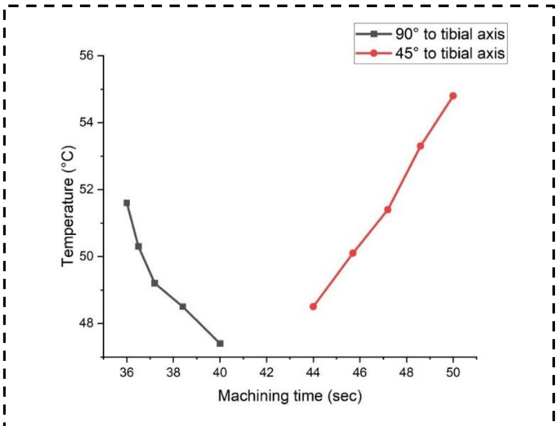

Fig. 6. Machining time vs Temperature, drill at Proximal region of tibia

There will be some additional factors to take into account for the work being done here because, as the pilot notes, lengthening the machining process also creates heat causes in skeletal tissues. Temperature and machining time were recorded for the same operation at several points on the bone surface. The temperature of the 90^0 cutting angles for the three sections of the bovine bone falls as the machining time increases. Similar to this, the temperature of the proximal and distal regions of the bovine bone at a 45^0 cutting angle drops as the machining time increases. In contrast, the temperature of bovine bone rises as the machining time increases in the middle of the bone.

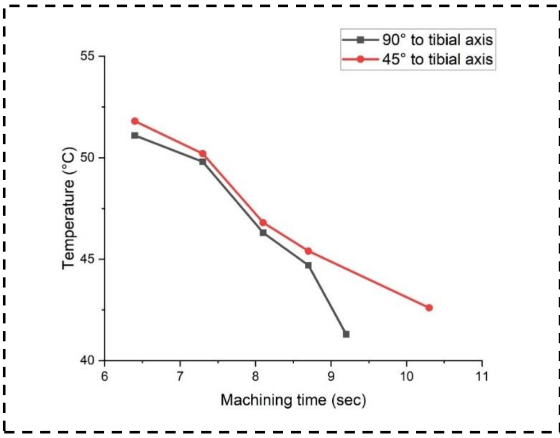

Fig.7. Temperature vs machining time drill at the mid-region of the tibia

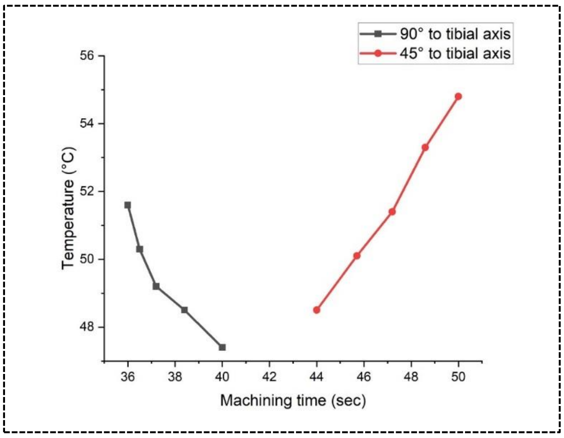

Fig. 8. Temperature vs Machining time drill at the Distal region of the tibia

With respect to the various implant surfaces, there was a substantial temperature increase in this investigation at the 45^0 cutting angle compared to the 90^0

cutting angle, indicating that there would be a minimal thermal energy gain at 90^0 with the duration of the drilling technique. As seen in the aforementioned graphical representations, the machining of bone depends on both thermal elevation and machining time.

3.3 *Spindle Speed vs Machining Time*

Another co-factor that will be important independent of the process parameters is shown to have an impact on bone drilling: thermal elevation. This was entirely reliant on the parameters of the surgical drilling process, but since spindle speed was the main finding of the study, we will just talk about it here. It is explained below how it will impact the surgery.

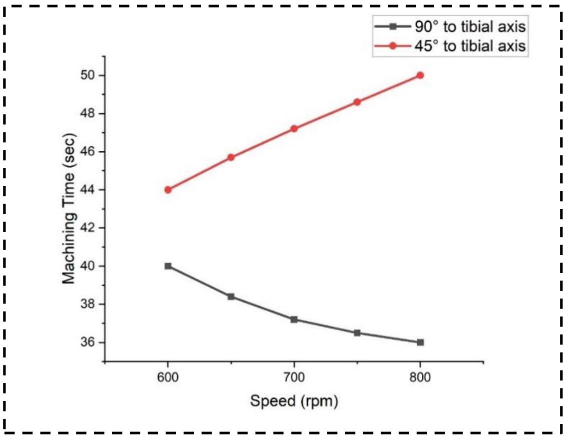

Fig.9. Spindle speed vs machining time when drilling at the Proximal region of the tibia

According to the experimental study conducted, increasing spindle speed is observed to correlate with a 45^0 to the tibia axis, which causes a significant increase in machining time on the proximal region of the bone sample. Based on the experimental study conducted, the results will change in some way with a variation in the implant site. The relationship between spindle speed and machining time at the specimen sample's mid-diaphysis is depicted in Fig. 10. The machining time was longer when the spindle speed was low, but it rapidly dropped as the cutting angle rose to 45^0, where it took longer than at 90^0. For proper understanding, these results are displayed below. The distal portion experiences the same problem with the 45^0 cutting angle and superior thermal decrease greatly on 90^0 with the machining time with heating rate as with the proximal region. It has a homogeneous thermal reduction in the machining at the mid-diaphysis with various cutting angles for the full process parameters.

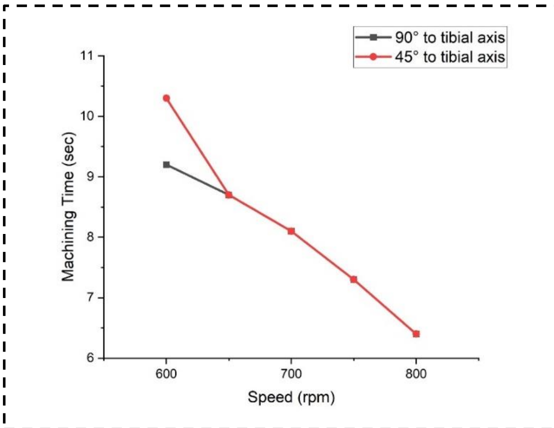

Fig10. Spindle Speed vs Machining Time when drilling at the Mid-region of the tibia

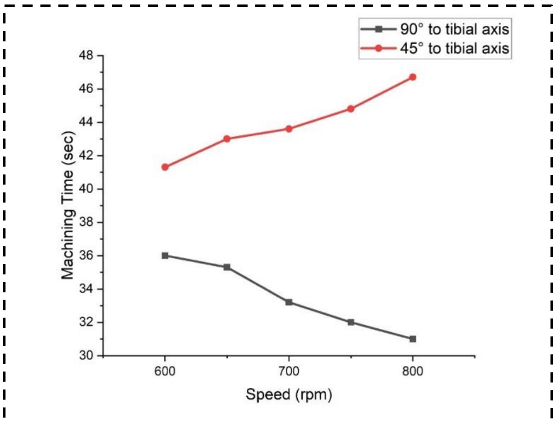

Fig.11. Spindle Speed v Machining Time when drilling at the Distal region of the tibia

Fig. 10 shows that the mid-diaphysis of machining time on speed, which moderately decreased gradually with 90^0 and 45^0. The machining times will differ significantly if you distinguish between 90^0 and 45^0. The 90^0 cutting angle was used here more frequently than the 45^0 cutting angle at the distal region. According to an experimental investigation, the entity of the full speed over to matching time significantly impacts the 45^0 cutting angle over 90^0. Based on the results we have some discussions on the in-vitro study. The mid-diaphysis will see reasonable temperature variations uniformly across the process parameters, in contrast to the proximal and distal sections, which will both experience significant temperature rise from the entire experiment. The ideal place to use the various cutting angles for drilling holes in the implant surfaces was the mid-diaphysis. In this investigation, increased cutting force and torque during bone drilling led to more microcracks [24], which reduced the strength of the implants that had to be done. Changes in temperature rise in the femur bone may be caused by various factors of process parameters in the study, with increased drill geometry and drilling type, irrigation [13, 14, 15], and with the cutting angle still being observed, the material removal rate will result in a significant loss of the bone graft. As such, the drilling type for the bone with various cutting angles needs to be researched. Despite the fact that the hollow tool used by Vishal et al., [23] al produced the least amount of decreasing torque and force when compared to the other bone drilling techniques and tools, there was hardly any Nano fibrillated visible during drilling in the pilot testing. The findings also indicate that temperature could be further lowered by utilising regular sterile saline for external watering. Since the heat produced by the irrigation method continuously evaporated, a significant reduction in temperature rise will be accomplished.

4. Conclusions

This study looked at how different types of bone drill instruments and techniques affected the cutting angle, the location of the implantation, and the temperature change. The experiment involved conventional drilling of bovine bone coupled with a novel combination of process parameters and a novel drill geometry. The experiment's findings have produced the following conclusions:

1. Using the three implant surface placements and the two cutting angles, an increase in temperature was seen as the drilling process progressed.
2. As was the case with the proximal and mid diaphyses, which were both significantly elevated in this implant position with a rise of 45^0 over 90^0, the mid diaphysis region demonstrated optimal results with the mild temperature rise.
3. The link between temperature and machining time was used to define the implant site as a standard zone. It was discovered that the cutting angle of 90^0 was superior to 45^0 for the best temperature reduction in the proximal region.
4. The results demonstrate that machining time on speed also contributes to temperature rise, with decreasing machining times with speeds at 90^0 cutting angles but noticeably increasing times with speeds at 45^0 cutting angles in the upstream and remote regions.

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