

Temperature Measurement of Conventional and Vibrational Bone Drilling during Implantation Technique - An In-Vitro Study

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Abstract

Bone drilling is the most common surgical technique in dentistry. The temperature will rise due to the forces and friction involved in drilling. As the temperature at the drilling site increases above the critical temperature, thermal necrosis occurs (47°C). Thermal injuries, such as osteonecrosis, implant failure, and other complications, are linked to it, as is poor surgical treatment. In this proposed study to test these hypotheses, a thermocouple and a thermal camera will be used during the process of drilling (FLIR E5 XT Thermal Imaging Camera). Vibrational and conventional drilling tests were performed on a bone model, and the thermal changes of the bone and drilling bit were recorded. According to the findings of the statistical study, in conventional drilling study the temperature rise of the bone model and drill bit is directly related to the depth of drilling. As the rotational speed of the drill increases in relation to the depth of the hole, the drilling temperature rises. The experimental results with vibrational aid showed that the temperature was lower than the conventional method. Vibrational drilling is expected to reduce thermal necrosis and to contribute to postoperative recovery during dental surgery.

Keywords: dental implant, drilling speed, drilling depth, temperature rise.

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1. INTRODUCTION

Oral health has the potential to cause significant pain and discomfort as well as distress, bad oral health may cause people significant pain and either injury or death in the worst-case scenario. On a worldwide basis, annual basis, approximately 450,000 Osseo integrated dental implants are placed, with an overall success rate of about 95%, with no major complications. Dental implants are implanted surgically into the mandible (jawbone). It is invasively repaired by drilling into the jawbone and inserting a screw into the implant site on the body^[1]. Despite dental

implants' high success rate, some patients experience implant failure. Dental implants are estimated to fail between 5% and 10% of the time, either immediately or months or years later. In spite of dental implants' impressive results, failure still occurs. The failure rate of dental implants is between 5 %and 10 %.

The drilling operation can cause a temperature rise during the implantation procedure. Heat is transmitted partly via the bloodstream and interstitial fluid, according to human physiology. Human bone, on the other hand, has a poor conductivity, with cortical bone having a conductivity of 0.38 to 2.3 W m⁻¹ K⁻¹ [2]. This could cause the temperature of the drilling site to rise, requiring a shift in the composition of bone substances like Alkaline Phosphatase. The essential bone material changes, causing necrosis, cell death, and a loss of mechanical strength at the drilling site [3]. As a result, the temperature at the drilling site must be held below a critical amount [4-6]. This temperature rise can be mitigated in a variety of ways. Bone remodelling, a body self-repair process, aids in bone reformation by osteoblasts at the same or different sites [7-8] and aids in the repair of thermal damage. To minimise temperature fluctuations, irrigation (coolant) is often used in combination with different dental procedure devices, such as those used for cutting, drilling, and vibrating [9].

A variety of technical factors influence the thermal changes that occur during implant site drilling, including rotational speed of drilling machine, load or pressure, adopted drilling technique, depth of drilling, irrigation used, drill material, drill design, drill wear, and drill shape [10]. As a result, it is critical to monitor the rate of temperature increase. Numerous studies and investigations are being conducted to ascertain the characteristics of the bone temperature at the drilling site. The proposed setup makes use of a thermocouple and a FLIR camera to monitor temperature rise in an invasive and non-invasive manner, respectively. The advantage of using a FLIR thermal camera is that it can monitor thermal variation at the drilling site and at the location of the drill bit [11]. On the other hand, thermocouples are used to accurately record numerous localised point locations' temperature since accurate recording requires direct contact with the object. On the contrary, the temperature of the drill bit cannot be determined using a thermocouple and is often classified as an invasive method of measurement. This technology, however, is now used for many in-vitro experiments as a result of its exactness in point measurement; the output is in millivolts and is located close to the drilling site [12]. Polyurethane is frequently treated to look and feel like bone. For research purposes, it can vary the density of the foam from healthy to osteoporosis. Since the experiment was done on a synthetic block, no ethical approval was needed [13]. The primary objective of this research is to determine the amount of heat generated during drilling operations. Numerous researchers concluded that while drilling precision factors such as sharpness and cutting tool have an effect on temperature, there is no direct correlation between temperature changes and driller material [14-16]. However, different dental drill designs produce distinct mean thermal variations. According to a study, twisted blades have a lower temperature variation than straight blades. Several experiments have been carried out to see how successful the temperature reduction is. One such inquiry is the addition of axial vibration to the drill bit [17-19].

1.1 Novel Contributions and Objectives of the Study

Numerous studies on bone drilling parameters have been published over the years, including several excellent review papers. According to dental research, increasing rotational speed reduces heat generation. Dental burs, on the other hand, operate at speeds ranging from 3600 to 7500 revolutions per minute, while orthopaedic drills operate at speeds ranging from 60–800 revolutions per minute. Additionally, the forces used vary, with dental forces ranging from 6–24 N and orthopaedic forces ranging from 60–120 Complicating comparisons. The two situations are not comparable. Several orthopaedic researchers have been unable to prove a connection between drill speed and temperature elevation [20].

This paper's goals and objectives can be summarised as follows:

- To calculate the temperature difference between the bone model and the drill bit while drilling at different speeds and depth.
- Temperature measurements of the bone model and drill bit are investigated after axial vibration is applied.
- Develop recommendations for reducing thermal damage during drilling, both in terms of speed and depth.
- To compile suggestions for reducing thermal damage by altering traditional drilling techniques.

2. MATERIALS AND METHODS

2.1. Experimental setup

To perform the bone drilling tests, a collection of equipment has been used as shown in Fig.1. This study used a FLIR E5-xt infrared camera with a temperature range of -20°C to 400°C (-4°F to 752°F), a thermography resolution of 19,200 (160 x 120) pixel infrared detector, and increased heat sensitivity of 0.1 °C to measure the thermal variance of the drilling method. The FLIR camera player is computer software that allows you to capture and watch videos. According to the available protocols, a thermocouple is mounted 0.5 mm off the hole wall with varying depths, as shown in Fig.1. The thermocouple is a K-type thermocouple with a millivolt output and a temperature measurement range of -20 to 1000 degrees Celsius. On a polyurethane bone model with properties identical to those of a D1 bone, a regular twisted surgical drill bit coated with titanium with a diameter of 2mm*21mm was used in this analysis. A number of vibration motors with varying vibration intensity and frequency are used to investigate the drilling impact temperature.

2.2. Materials

A comparison between the thermocouple and the FLIR camera (FLIR E5 xt thermal imaging camera) is conducted in this thermal monitoring study, with the thermocouple serving as the reference and recording the temperature at a distance of 2mm from the work area. It is classified as invasive temperature monitoring. Due to the fact that thermocouples cannot be used at the drilling site, a FLIR thermal camera is used to provide non-invasive temperature increase at the location. This allows for real-time monitoring of thermal variation caused by varying the speed of the hand piece and the depth of the bone model. FLIR thermal camera is a small, pocket-sized, and portable thermal imaging device that produces a thermal image with a resolution of 16,384 pixels after interpolation. Temperatures range from -30 to 650 degrees Celsius. At -10°C, the precision is 1.5°C or 1.5 %of the 2.0°C reading. The resolution of the display is 0.1°C, while the optical resolution is 30:1. It is uncomplicated, astute, precise, and adaptable ^[11].

A digital millimetre with auto-range is a test instrument that can measure more than two quantities simultaneously, such as current and temperature. The model DT-17N incorporates a thermocouple function that enables temperature sensing; its operating temperature range is 20 to 100 degrees Celsius. 0-10 a voltage, current range the conversion of double integral A/D signals ^[21] is automatic and requires no adjustments.

A titanium-coated, twisted drill with dimensions of 2mm*21mm is used because the contact area between the drill and the bone is often considered a factor in heat ^[22].Drilling was carried out on a rigid polyurethane bone model (M2021) with dimensions of 20*20*50mm; polyfoam is not subject to the stringent regulations applicable to cadaver bones and is resistant to moisture and mould. Numerous studies have demonstrated that polyfoam is a suitable mechanical substitute for human cancellous bone, as well as a substrate for implant testing. Polyurethane is frequently used to replicate the compressive strength and coefficient of elasticity of bone. It can be used to simulate healthy bone, and by varying the density of the foam, it can be used to recreate conditions such as osteoporotic bone for research ^[23-24]. The American Society for Testing and Materials (ASTM) has designated rigid polyfoam as a standard material for orthopaedic device and instrument testing (ASTM, 2012).

The Marathon Hand piece Micro motor was used for bone drilling; it is a compact and portable micrometre with 2.9 N-cm of torque, 45 watts of power, a maximum speed of 35,000 revolutions per minute, the ability to angle the straight hand piece for the desired purpose, and continuous variable speed control. An accelerometer (vibration motor) is a small unbalanced mass connected to a direct current motor that generates vibration. It is connected to an Arduino UNO, a microcontroller board with 14 digital pins that operates at 5V, and the output is in the form of vibration with varying delay times, frequency, and amplitudes [42]. The model numbers Z30F4B8196813L, Z4FC1B1301781, Z43FM1B8230001L, and Z6CL2A0080001 are associated with various rpm values (20 Hz A=250, 25 Hz A=280, 25 Hz A=330, and 30 Hz A=350). It was attached to both the bone model and the hand piece during drilling to determine whether vibrations had an effect on thermal variation. The temperature of the environment has a significant impact on thermal images. To minimise the effect of thermal infrared radiation, a collapsible enclosure was used in this research as shown in Fig.2. and Fig.3. [25].

2.3. METHODS

2.3.1. Conventional drilling

The temperature rise caused by the bone drilling process was investigated and analysed in this study using an infrared camera and thermocouple as shown in Fig.4. Rotational speed and depth of drilling were chosen as input parameters for this purpose because they have the greatest effect on temperature rise. Due to the study's primary focus on conventional drilling, the rotational speed range was set to 3000–7000 r min⁻¹ with 500 r min⁻¹ intervals. For drilling depth 3mm, 6mm and 9mm have been considered. Different drilling parameters are shown in Table.1.

As a result, the test designs included nine rotational speed states and three drilling depth states, for a total of 27 experimental states to be investigated. Each test has been repeated ten times. Between tests, an appropriate interval has been considered to allow the drill bit temperature to return to room temperature. The infrared camera works on the theory of heat transfer through radiation. The emissivity coefficient has a major impact on the heat transfer rate, according to the Stephen-Boltzmann relationship. To ensure that the camera records the correct temperature, the emissivity coefficient should be manually set. According to available protocols, the thermocouple was implanted at a various depth (5mm, 10mm) and 0.5 mm from the hole wall.

2.3.2. Vibrational Drilling

The bone model is subjected to axial vibration, and the temperature of the corresponding bone model is determined using a thermocouple and a thermal camera. For just 9mm driller depth, the test designs included 9 rotational speed states and 4 different vibrational states. There are a total of 36 experimental states to investigate. Each test has been repeated ten times. Table.2 lists the various drilling frequencies that were used in this analysis.

3. RESULTS

This study conducted 630 experiments utilising two distinct drilling techniques: 27 conventional drill tests and 36 vibrational drill tests. Ten drills were allocated to each method.

3.1 Conventional Drilling

The higher the temperature elevation, the deeper the drilling is performed with an increasing rotational speed. The temperature trend will descend as drilling speed increases until a certain speed is reached, at which point it will begin to rise as shown in Fig.5. Furthermore, the probability of hitting critical temperature increases as drilling depth increases. The same temperature pattern has been observed at almost all depth of drilling. The same test has been recorded with thermography camera Figure.6. depicts the findings of thermography. Thermography and thermocouple detection are related. As a result, we can conclude that

thermography is the most effective non-invasive way to monitor the temperature of bone drilling is shown in Fig.7.

3.2. Drill bit temperature rise.

The deeper the drilling is done with a rising rotational speed as the temperature rises. As drilling speed rises, the temperature of the drill bit will decrease until a certain speed is reached, at which point it will begin to rise. At almost every depth of drilling, the same temperature trend has been observed. As compared to the temperature elevation of the bone model, the driller bit temperature with thermography has a higher value as shown in Fig .8. Because given the temperature variations with bone depth, heat was generated primarily at the drill tip, where the most friction and compressive forces are applied [26].Furthermore, as drilling depth increases, the likelihood of reaching critical temperature rises.

4. DISCUSSION

4.1. Experimental results analysis from the machining mechanics aspect

A significant portion of the energy added to the device for chip removal is converted to heat during the machining process. This heat escapes the machine in three ways: some heat is transferred to the work piece, increasing its temperature, some heat is lost through the exhaust, and some heat is retained in the form of machining chips. This raises the temperature of the tool. In drilling operations, increasing the rotational speed of the drill bit facilitates chip formation and reduces machining forces. This results in a decrease in temperature. Drilling to a greater depth prolongs the operation and decreases the amount of chip evacuation. The tool (driller bit) heats up as a result of this. The temperature of the bone model and driller bit rises as the rotational speed and drilling depth increase. As a result, when high values of rotational speed and drilling depth are used in bone drilling operations, the risk of thermal necrosis and orthopaedic surgery failure is greatly increased.

4.2. The bone model and driller bit temperature elevation in conventional drilling: a statistical analysis

The bone and drill bit temperature rise experimental and statistical results showed that raising the drill bit rotational speed allowed for faster heat evacuation from the machining system, resulting in a lower bone temperature rise. This effect is based on a decrease in machining forces and chip evacuation speed, as well as an increase in the share of heat introduced to the drill bit, all of which are dependent on increased rotational speed in terms of machining mechanics. However, as drilling depth increases, the amount of chip evacuation decreases, increasing the bone model and tool sharing heat as shown in Table.3. Thermal necrosis is more likely as a result of this.

When drilling to a depth of 9mm at a speed of 4000 rpm, the temperature of the driller bit and bone model increases rapidly at first, and then gradually decreased before rising again. The mean maximum temperature was 39.2°C, with a standard deviation (SD) of 3.391 reached in 7 seconds. The thermocouples in the bone, on the other hand, reached their maximum temperature (mean 48.2 SD 2.822) after 11 seconds.

When drilling to a depth of 9mm at a speed of 6000 rpm, the temperature of the driller bit and bone model increases rapidly at first, and then gradually decreased before rising again. The mean maximum temperature was 46°C, with a standard deviate on(SD) of 1.093 reached in 7 seconds. The thermocouples in the bone, on the other hand, reached their maximum temperature (mean 54.13 SD 1.335) after 13 seconds.

When drilling to a depth of 9 mm at a speed of 7000 rpm, the temperature of the driller bit and bone model increases rapidly at first, and then gradually decreased before rising again. The mean maximum temperature was 47.9°C, with a standard deviation (SD) of 1.033 reached in 7 seconds. The thermocouples in the bone, on the other hand, reached their maximum temperature (mean 54.13 SD 1.335) after 11 seconds.

When the rotation speed of the drill increased, the maximum drill temperature increased quickly within 6-7 seconds, whereas the temperature measured within the bone model takes 11-13 seconds to reach maximum temperature. The thermocouple in the bone and driller bit reached the maximum temperature shown in Fig.9 at a depth of 9mm. We confirmed that maximum temperatures varied with depth ($p < 0.03$) and that maximum values differed statistically significantly at each rotating speed.

4.3. Statistical study of the bone model temperature elevation in Vibrational assisted drilling

According to previous research, drilling to a depth of 9mm induces a higher temperature rise. So, vibrational aided dental drilling is done to a depth of 9mm with a variety of rotational speeds and vibrational frequencies. As can be seen in Table.4, the mean temperature of the drill hole decreases as the vibration level rises. With rising vibrational frequency, approximately 20% of the temperature is decreased. Furthermore, as compared to traditional drilling, vibrational drilling can substantially reduce cutting heat in cortical bone drilling ($P < 0.01$).

In machining applications, vibrational drilling has been shown to have strong advantages over conventional drilling [27-31]. In research, high-frequency vibration pulses have been shown to have a significant impact on reducing bone cutting heat [32, 33]. When drilling a bone model, vibrational drilling, according to Table.4, can greatly reduce cutting heat. We assume this is because vibrational drilling decreases the amount of time the drill bit is in contact with the drill hole and encourages air movement in the hole, which helps to dissipate some of the cutting heat.

5. CONCLUSIONS

Changes in the temperature of the bone and drill bit during drilling operations were determined using infrared thermography and a thermocouple under various conditions of rotational speed and depth of drilling. The accuracy of infrared thermography was confirmed by comparing experimental results to thermocouple temperatures. Elevating the rotational speed, on the other hand, allows a greater share of heat to be evacuated through the chips by reducing machining forces and increasing chip evacuation speed. As a result, increasing the depth of drilling and rotational speeds raises the temperature of the bone, increasing the risk of thermal necrosis. The application of the drilling depth determines the temperature elevation and drilling time as a guideline for use in dental surgery. Modifications to existing drilling methods, such as vibration assisted drilling, resulted in a significant reduction in temperature elevation. As a result, the vibration-assisted technique offers a wider range of temperature reduction with different rotational speeds and drilling depths. This clinically relevant research setup will serve as a model for developing a more practical implant drilling technique that prevents thermal necrosis in a variety of clinical scenarios.

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Table.1. Operating conditions for bone drilling

Rotational Speed, N(r/min)	3000-3500-4000-4500-5000-5500-6000-6500-7000
Depth of Drilling (mm)	3-6-9
Drill bit diameter (mm)	2.0 x 21

Table. 2. Operating conditions for vibrational assisted drilling

Bone drilling Operational Parameters for Vibrational assisted Drilling	
Rotational Speed, N(r/min)	3000-3500-4000-4500-5000-5500-6000-6500-7000
Depth of Drilling (mm)	9mm
Vibrational frequency and Amplitude	A=250mv,f=20 Hz ; A=280mv,f=25Hz; A=300mv,f=25 Hz ; A=350mv, f=30 Hz ;
Drill bit diameter (mm)	2.0 x 21

Table.3. Mean Temperature as a function of drill speed and depth.

Rotational Speed (N)r/min	Bone Temp(Thermocouple)			Driller Bit Temp(IR)		
	3mm depth	6mm depth	9mm depth	3mmdepth	6mmdepth	9mmdepth
3000	34.1±0.76	38.2±4.82	42.5±5.64	42.0±3.14	48.0±6.28	50.0±5.72
3500	33.5±2.78	37.6±3.22	41.6±3.25	40.8±3.86	47.2±2.70	49.1±6.20
4000	32.6±1.26	36.9±3.12	39.2±3.39	39.8±2.40	47.0±2.78	48.2±2.82
4500	31.5±0.87	35.4±1.04	40.8±1.07	39.1±2.21	45.8±0.60	50.2±0.70
5000	30.9±0.60	37.2±0.87	42.7±0.83	38.4±0.90	48.3±0.76	52.9±0.55
5500	30.1±0.76	38.9±1.27	44.1±0.86	40.2±0.55	49.6±0.98	55.2±1.12
6000	35.6±0.98	41.3±1.03	46.7±1.09	42.6±0.89	50.7±1.09	54.1±1.33
6500	37.9±1.18	41.8±0.81	47.1±1.25	43.9±0.75	53.5±0.99	55.7±0.85
7000	38.2±1.00	44.6±1.76	47.9±1.03	45.1±0.86	55.1±0.98	57.3±1.10

Table .4.The mean temperature (°C) of drill hole and the P value for every group.

Drilling parameters	Conventional drilling	Vibrational Drilling			
		A=250mv,f=20 Hz	A=280mv, f=25Hz	A=300mv,f=25 Hz	A=350mv, f=30Hz
Mean temperature ± SD(Thermocouple)	43.653±3.802	36.212±2.542	35.777±2.5760	35.351 ±2.623	34.4604±3.324
Mean temperature of drill hole ± SD(Thermography)	44.450±3.860	36.833± .740	36.403±2.67852	35.991 ±2.789	34.997 ±2.680
p value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Fig.1.Experimental setup for dental drilling temperature acquisition systems

Fig.2. Collapsible enclosure for thermography image acquisition

Fig .3. Thermal camera with collapsible enclosure

Fig.4. Bone drilling setup and IR acquisition through collapsible window

Fig.5. - Conventional Drilling on Bone Model Temperature acquisition by Thermocouple

Fig 6- Conventional Drilling on Bone Model Temperature acquisition by FLIR Camera

Fig 7- Thermography image of Bone model and Driller Bit

Fig .8- Conventional Drilling temperature acquisition on driller bit using FLIR Camera

Fig .9. Time pattern for various drilling depth

MANDIBULAR DRILL TEMPERATURE DATA ACQUISITION BLOCK DIAGRAM





