Investigation on The Effect of Drill Diameter During Bone Drilling for Surgery Applications

By

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ABSTRACT

Drilling through bone is an effective method to get rapid cure for bone injury. During orthopedic surgery there is a need to fix the bones at their right position so that it can heal at its natural position correctly. Bones can be fixed with a lot of possibilities such as implants and screws for the overall curing process. Therefore, drilling through bone is a necessary action to fulfill this objective. The drilling mechanism for bone drilling is the same as the mechanical drilling procedure. So the drill-bit and its specifications used during bone drilling affects the surroundings wither by surface roughness, necrosis or the accuracy of the drill or a lot of other things.

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CHAPTER 1 - INTRODUCTION

1.1 Bone Definition and Properties:

Bone is considered a type of connective tissue that consists of Calcied material. There are two types of bone tissues in human's body, the cortical bone which is the outer hard layer and the cancellous which is the inner spongy layer (Fig.1.1). Periosteum is a hard covering osteogenic connective tissue that covers the outer surface of the bone while the bone marrow is located inside the bone its self. Most of the inside of a bone is hollow. Endosteum is an osteogenic similar cell that lines the inner surface of the bone. Periosteum and the endosteum contain the vascular system which supplies the bone with nutrients and oxygen for bone growth and repair.

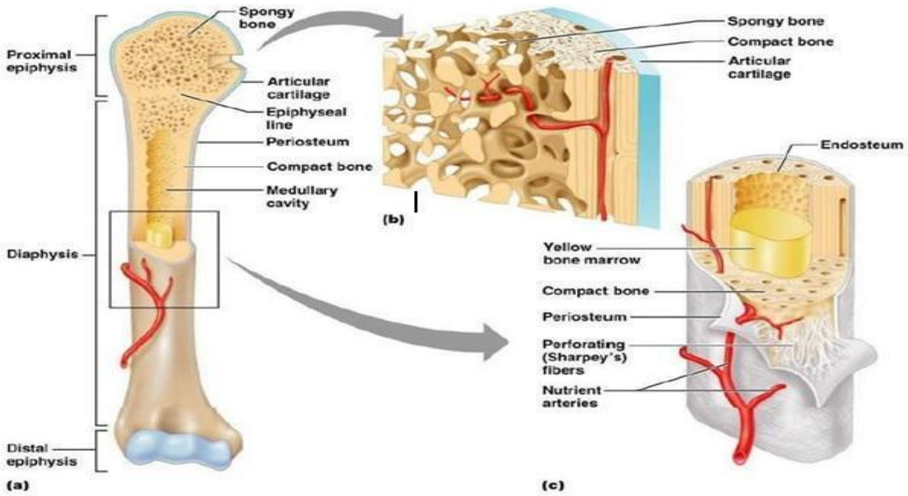


Fig. 1.1 (a) Human cortical bone, (b) Cancellous bone (Inner spongy bone structure), (c) Cortical bone (Compact bone): outer layer of bone structure

Compact bone and trabecular bone almost have the same composition, even arthritic bone, in animals, has a similar composition with calcium at 73% and phosphorus at 27%.

1.2 Background

Bone fracture is a normal life incident due to accidents or the process of aging. When a bone is broken the periosteum and endosteum provide bone-forming cells, which work to bridge the fracture. Normally, the fracture of bones is usually managed by drilling the bone at required locations for screw insertions and fixation plates. The cutting of bone is one of the oldest surgical procedures in the history of medicine.

Mechanical properties of the bone depend on their composition and structure, which includes the arrangement of the elements and the type of bond between the fibers and matrix. For example, the arrangement of fibers is different in several types of bones, which gives rise to distinct properties.
Here are some properties of the bone as known:

- **Shear strengths:** Is the strength of a material or component against the type of yield or structural failure where the material or component fails in shear. A shear load is a force that tends to produce a sliding failure on a material along a plane that is parallel to the direction of the force. Bone fails more rapidly when exposed to shear strength rather than when being exposed to compressive or tensile strength. The shear strengths are responsible for problems in the vertebral discs. Shear strength may cause spondylolisthesis, where one vertebra slips over the previous one.
- **Elasticity**: Is the ability of a deformed material body to return to its original shape and size when the force causing the deformation is removed. When the load is first applied, a change in the length or the angel of the bone appears. The bone can be deformed up to 3%. This is considered the elastic amplitude of the stress-strain curve because, when the load is removed, the bone recovers and goes back to its original format or extent.

- **Plasticity**: With the continuous placement of load on the bone tissue, it reaches the deformation point, after which the external fibers of the bone tissue will start to give up, experiencing micro-breaks and disconnection of the material that lays inside the bone.

- **Anisotropic Characteristics Bone tissue**: The bone is strong to support loads in the longitudinal direction because it is designed to handle loads in that direction.

- **Viscoelastic Characteristics**: The bone is also viscoelastic, which means that it responds according to the speed to which the load is applied and the amount of the load.

- **Hardness**: The hardness, or elasticity module of material, is determined by the decrease of the load-deformation curve during the amplitude of the elastic response deformed. This response occurs in many materials, including bones, tendons and ligaments.

- **Tensile Strengths**: A tensile strength is usually applied to the bone surface where it pulls or elongates the bone, tending it to extend and slim the bone. The maximum stress, is perpendicular to the applied load. The source of tensile strength is usually the muscles.

- **Bending Strengths**: A bending strength is the load applied to an area that has no support offered by a framework, causing the bone to bend and deformation occurs. One side of the bone will be convex in which will have tensile forces, while the other side will be concave where compressive strengths are present. Normally, the bone will fail and break from the convex side in response to high tensile forces since the bone can handle huge compressive forces compared to tensile.

1.3 Problem Statement

In this investigation the purpose is to see the effect of the same drill-bit type but with different diameters on the bone based on the surface finish, quality of the drill and effectiveness.

1.4 Objectives

The main objective in this research is to investigate the effect of different drill-bit diameters effect on

- Surface finish
- Surface integrity
- Surface roughness

1.5 Scope of study

The study is limited to investigate 3 various processing parameters, which are Drill diameter, feed rate and the number of revolutions per minute of the dill-bit then it is going to study the effects of the process parameters on the specimen.

CHAPTER 2 – LITRETATURE REVIEW AND THEORY

Bone cutting is one of the oldest surgical operations in the history of medicine. Nowadays, knee and hip implant surgeries are performed around the world and considered to be among the most commonly performed operations in medical practice. In the past years a lot of work has been done to investigate and analyze the effect of various machining methods on bone during surgery.

The literature review has been divided into two parts. First part is conventional techniques for the bone drilling and second part shows some results of non-conventional techniques of drilling.

2.1 Conventional Drilling

Mustafa et al. (1995) carried out an investigation on the effect of force on the drill speed and the energy consumption during the drilling process. Applied force, energy consumption and drill speed were measured while drilling in a bovine cortical bone specimen. A commercial surgical drill was fixed with a custom-design speedometer for measuring the rotational speed. Tests were conducted of forces between 1.5 to 9.0 N and for speeds ranging from 20,000 to 100,000 rpm (Fig. 2.1). The measurements of electric power showed that the total energy consumed, decreased with respect to speed and force, mainly due to decreasing the drilling time. The decreasing in energy suggested that drilling at high speeds with large forces applied may be desirable due to reduction of the bone temperature.

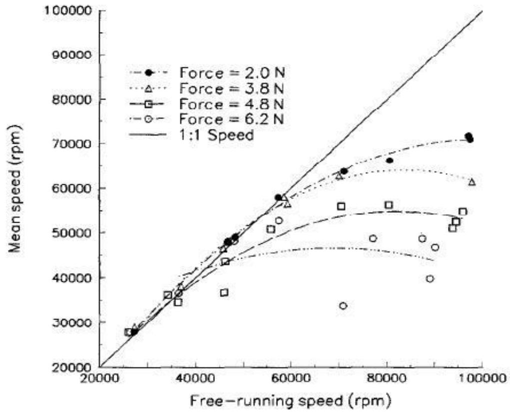


Figure 2.1: Variation in free running speed on application of force (Mustafa et al. 1995)

Colin Natali et al. (1996) studied the various engineering drill bits available in market and compared them to standard orthopaedic bits thru continuously recording temperatures at distances of 0.5 mm, 1.0 mm and 1.5 mm from the edge of a 2.5 mm hole drilled in fresh cadaver human tibia. Some commercial drill bits managed to perform better than the orthopaedic equivalents, producing significantly less thermal damage to the surrounding bone and lowering the force required for cortical penetration to half. The ideal bit for orthopaedic purposes should have a split point tip and a quick helix angle. Hypothetically, the addition of a parabolic flute will further enhance coping with thermal damage during cutting .

K. Alam et al. (2009) investigated the effects of two drilling techniques on surface roughness of the drilled holes. The set up used for UAD has been shown in Fig. 2.2. The surface roughness produced by ultrasonic assisted drilling (UAD) and conventional drilling (CD) were measured and tested with various contact and non-contact methods (Fig. 2.3). The difference in surface roughness between both drilling techniques were explained by high-speed filming the whole processes.

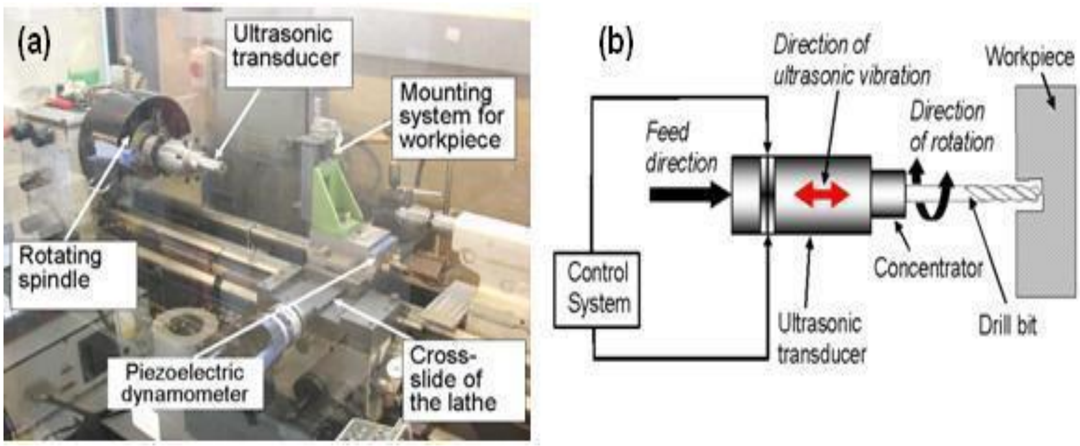


Figure 2.2: Set up used for ultrasonic assisted drilling of bones (K. Alam et al. 2009)

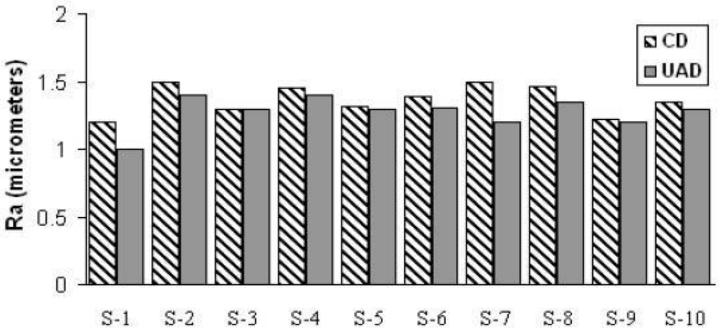


Figure 2.3: The difference in surface roughness obtained by Conventional Drilling and Ultrasonic Assisted Drilling (K. Alam et al. 2009)

F. Karaca et al. (2011) carried out a study by considering the bone mineral density, bone sex, drill tip angle, drill speed, drill force and feed-rate. The specimens were taken from the drilled sites of fresh male and female calf tibias. The temperature changes at the drill site were investigated throughout the statistical and histopathological analysis. It was observed that the temperature increased with an increasing drill speed and decreased with high feed-rates and applied drill forces. The drilling temperatures of the female bovine tibias were found to be higher than that of the male tibias and the drill speed was found to be a significant parameter on the maximum temperature. Moreover, the maximum temperature increased with an increasing drill tip angle and bone mineral density. The bone quality around the drill site was found to be worse than the bone samples exposed to low temperatures.

Lee et al. (2011) presented a mechanistic model for the bone drilling process to enable prediction of bone drilling forces as a function of drill-bit geometry and drilling conditions. It was seen that increased speed commonly results in lower drilling forces. However, high speeds were observed to cause increased trauma. The effect of feed rate was also investigated; as expected, higher feed rates were seen to produce higher thrust forces and torques. The effect of drill-bit geometry on bone-drilling forces has also been investigated experimentally. Drill point angle has seen to have a strong effect on the drilling forces (i.e., sharper drill tip) were seen to produce lower forces; they also increased the unwanted drill breakthrough.

Lee et al. (2012) presented an experimental investigation of the effects of spindle speed, feed rate, and depth of drilling on the temperature distribution during drilling of the cortical section of the bovine femur (Fig. 2.4). In an effort to reduce measurement uncertainties, a new approach for temperature measurements during bone drilling is presented in this study. The new approach is based on a setup for precise positioning of multiple thermocouples, automated data logging system, and a computer numerically controlled (CNC) machining system. This study suggests that the exposure time during bone drilling far exceeds the commonly accepted threshold for thermal injury, which may prevail at significant distances from the drilled hole.

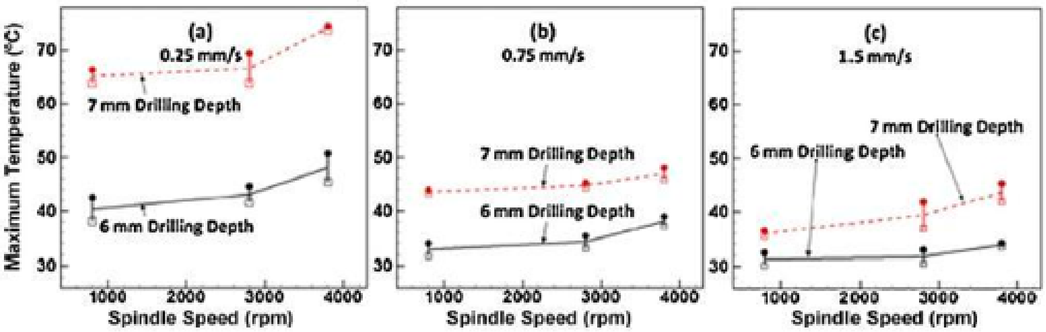


Figure 2.4: Maximum temperature at 3 mm depth as a function of the spindle speed for hole depths of 6 mm and 7 mm, and for an initial temperature of 26°C (Lee et al. 2012)

Sui et al. (2013) developed an improved mechanistic model to predict the thrust force and torque for bone-drilling operation. The cutting action at the drill point is divided into three regions: the cutting lips, outer portion of the chisel edge (the secondary cutting edges) and inner portion of the chisel edge (the indentation zone). Models that account for the unique mechanics of the cutting process for each of the three regions are formulated. The models are calibrated to bovine cortical bone material using specific cutting pressure equations with modification to take advantage of the characteristics of the drill point geometry. The models are validated for the cutting lips, the chisel edge, and entire drill point for a wide range of spindle speed and feed rate. The predicted results agree well with experimental results. Only the predictions for the drilling torque on the chisel edge are lower than the experimental results under some drilling conditions. The model can assist in the selection of favorable drilling conditions and drill-bit geometries for bone-drilling operations.

Tuijthof et al. (2013) tried to measure the influence of drill bit geometry on maximum thrust forces required for drilling, and compare this relative to the known influence of feed rate and bone composition. Blind holes were drilled perpendicular to the iliac crest up to 10 mm depth in cadaveric pelvic bones of 20 pigs (adolescent) and 11 goats (full grown) with eight substantially different drill bits of Φ3-3.2 mm. Subsequently, boreholes were drilled perpendicular to the ilium with the same drill bits at three different feed rates (0.58 mm/s, 0.83 mm/s, 1.08 mm/s). The mean maximum thrust force ranges from 10 to 110 N for cortical bone, and from 3 to 65 N for trabecular bone. The results show that both drill bit geometry and feed rate have a significant influence on the maximum thrust forces, with a dominant influence of drill bit geometry in terms of shape of the flutes, sharpness of cutting edges and value of point angle.

Pandey et al. (2014) used a modified algorithm (grey based fuzzy algorithm) to optimize multiple performance characteristics in drilling of bone. Experiments have been performed with different cutting conditions using full factorial design. The quality parameters considered are temperature, force and surface roughness. Grey relational analysis (GRA) coupled with fuzzy logic is employed to obtain a grey fuzzy reasoning grade (GFRG) combining all the quality characteristics. The highest GFRG is obtained for the feed rate of 40 mm/min and the speed of 500 rpm and is the optimal level. Analysis of variance (ANOVA) carried out to find the significance of parameters on multiple performance characteristics revealed that the feed rate has the highest contribution on GFRG followed by the spindle speed.

2.2 Non-Conventional Drilling

Schwieger et al. (2004) investigated whether the abrasive jet cutting quality in cancellous bone with a biocompatible abrasive is sufficient for the implantation of endoprostheses or for osteotomies. Sixty porcine femoral condyles were cut with an abrasive water jet and with an oscillating saw. Lactose-monohydrate was used as a biocompatible abrasive. Water pressure (pW = 35 and 70 MPa) and abrasive feed rate (m = 0.5, 1, and 2 g/s) were varied (Fig. 2.5). As a measure of the quality of the cut surface the cutting gap angle (δ) and the surface roughness (Ra) were determined. Abrasive water jets are suitable for cutting cancellous bone. The large variation of the cutting gap angle is, however, unfavourable, as the jet direction cannot be adjusted by a predefined value. If it is possible to improve the cutting quality by a further parameter optimization, the abrasive water jet may be the cutting technique of the future for robotic usage.

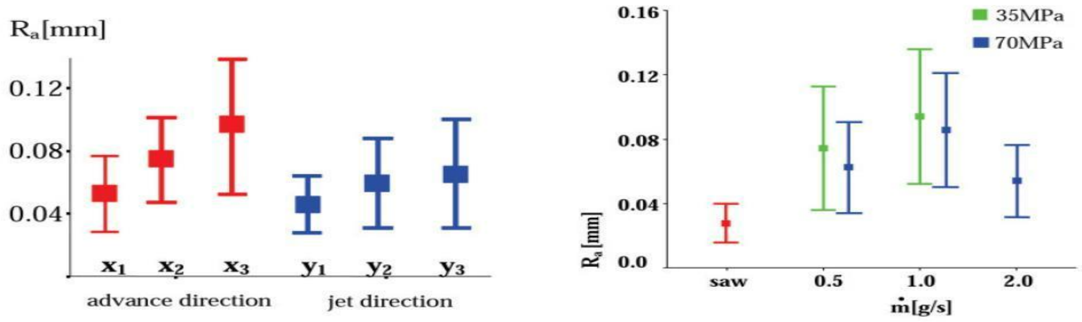


Figure 2.5: Variation in surface roughness depending upon the advance direction, jet direction & water jet pressure (Schwieger et al.2004)

Biskup et al. (2006) investigated to find out the feasibility of water jets for medical applications as water jets are mostly used for applications where no structural changes are allowed. For medical applications the critical temperature is much lower than for industrial use, because bones react very sensitively to heat. The damage to the tissue depends on the temperature and the time of exposure. The tissue is irreversibly destroyed after a period of approximately 10 seconds at 57°C. To avoid this effect, which causes the so-called necrosis formation, and which results in poor bone healing, heat management is required for water-jet osteotomies. The first step has been made in this paper. The heat generation during abrasive water-jet osteotomies was measured by thermocouples that were inserted into the cortical hollow bone segments of cattle. The influence of parameters like pressure, traverse rate, abrasive flow rate and abrasive material have been shown together with the influence of the location of thermocouples Fig. 2.6.

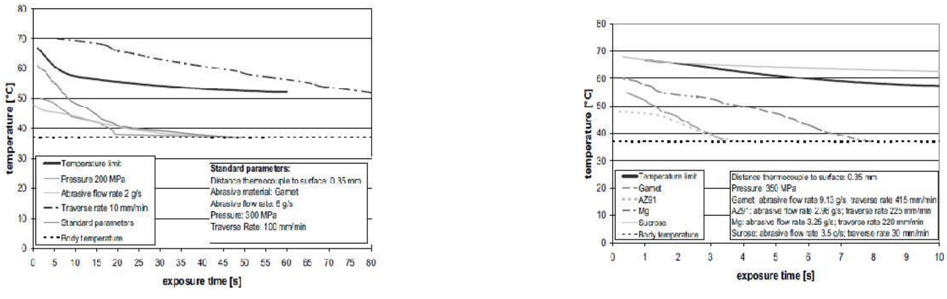


Figure 2.6: Effect of parameters on the temperature and the exposure time (Biskup et al. 2006)

Ozdemir et al. (2013) in this study tried to investigate the required time period of the Er:YAG laser that is used for drilling through cortical bone when pilot hole drilling is needed before mini screw insertion. Even though Er:YAG laser is used in various in vivo and in vitro studies, there is no accepted procedure of laser for depth control during drilling through cortical bone. The study sample consisted of 120 cortical bone segments having 1.5 and 2.0 mm of cortical bone thickness. An Er:YAG laser, with a spot size of 1.3 mm and an air–water spray of 40–50-ml/min, was used. The laser was held 2 mm away from and perpendicular to the bone surface with different laser settings. Twelve specimens were prepared for each subgroup. As the cortical bone thickness increased, the time needed to drill through the bone increased. Frequency increase directly caused a decrease in irradiation duration. When three different frequencies (10 Hz, 12 Hz & 15 Hz), three different energies (200 mJ, 300 mJ & 400 mJ) and four different power values (2.4W, 3W, 3.6W & 4W) were tested for both the 1.5- and 2-mm cortical bone thicknesses, the shortest duration needed to drill through cortical bone was seen in the 3.6W (300 mJ–12 Hz) setting (Fig. 2.7). When pilot holes are drilled prior to mini screw placement in 1.5 to 2 mm of cortical bone using Er:YAG laser, the most appropriate value is found with the 3.6W (300 mJ–12 Hz) setting.

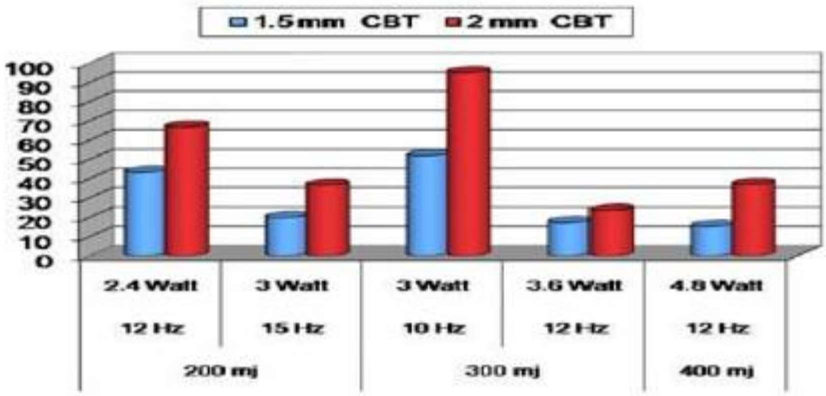
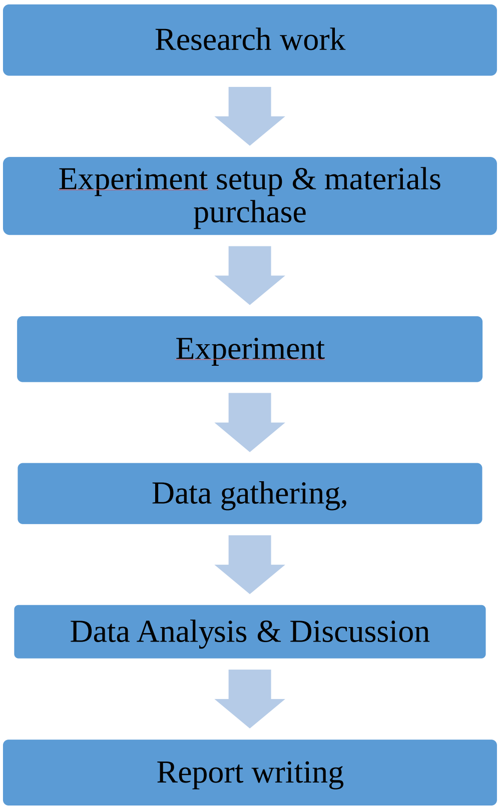


Figure 2.7: Schematic drawing of the mean values of the groups (Ozdemir et al. 2013)

Dunnen et al. (2013) carried out this study with the goal to deduce a descriptive mathematical equation able to predict the hole depth and diameter based on the local structural properties of the bone at given water jet diameters. 210 holes were drilled in porcine femora and tali with water jet diameters (D_{nozzle}) of 0.3, 0.4, 0.5 and 0.6

mm at a pressure of 700bar and a 5s jet time. Hole depths (L_{hole}), diameters (D_{hole}) and bone architectural properties were determined using micro CT scans. The most important bone architectural property is the bone volume fraction (BV/TV). Drilling to a specific depth in bone tissue with a known BV/TV is possible, thereby contributing to the safe application of water jet technology in orthopaedic surgery. Using water jets instead of rigid drill bits for bone drilling can be beneficial due to the absence of thermal damage and a consequent sharp cut. Additionally, water jet technology allows the development of flexible instruments that facilitate manoeuvring through complex joint spaces.

CHAPTER 3 - METHODOLGY



Drilling through bone is very common and simple as simple to drill any mechanical component, but it need proper care and patience. Mostely conventional method of drilling is in practice. Some other unconventional methods of drilling were also tried but not in use, due to some problems associated with them.

Methods of bone drilling can be classified in two major categories:

1. **Conventional drilling**
2. **Unconventional drilling**

Conventional Drilling

Conventional drilling is the very common used mechanical drilling process in which rotating drill-bit is used to produce hole in the specimen. Tool is rotating with the help of adjacent power system. With conventional bone drilling some parameters affects the efficiency and quality of drill hole.
These parameters are reported in two major categories:

1. Machining parameters
2. Drill specifications

These two categories can be broadly classified as some other direct parameters related to bone drilling. Machining parameters includes the variables within the drilling machine used in bone drilling and drill specifications include the permissible changes within the drill bit dimensions used during the done drilling. These two categories can be classified broadly in Table 3.1.

Table 3.1: Parameters affecting the bone drilling

Machining parameters	**Drill specifications**
Rotational speed	Drill diameter
Feed rate	Flutes and helix angle
Applied drill force	Drill wear
Cooling **1.** Internal cooling **2.** External cooling	Cutting edge angles **1.** Rake angle **2.** Clearance angle and flank
Drill depth Predrilling	Drill point **1.** Point angle **2.** Chisel edge

Machining Parameters

Drilling parameters are essential for controlling the temperature generated during drilling. Parameters associated within the setup of hand drill are the machining parameters and they are closely related with the drilling quality and precision. Thermal necrosis also depends on these machining parameters.
Rotational Speed, Feeding Rate and Force Applied.

In the last few decades many researchers have investigated on this aspect in order to minimize the chances of necrosis during drilling. Measure of drilling speed is in terms of revolution per minute (RPM). When one stationery and one rotating objects strike, heat is generated due to friction, so rotational speed should be so optimum to produce minimum heat. Researchers suggest different set of RPM for different conditions.
Using unrelated set of parameters can cause damage of drill-bit with in bone as shown in Fig. 3.1.

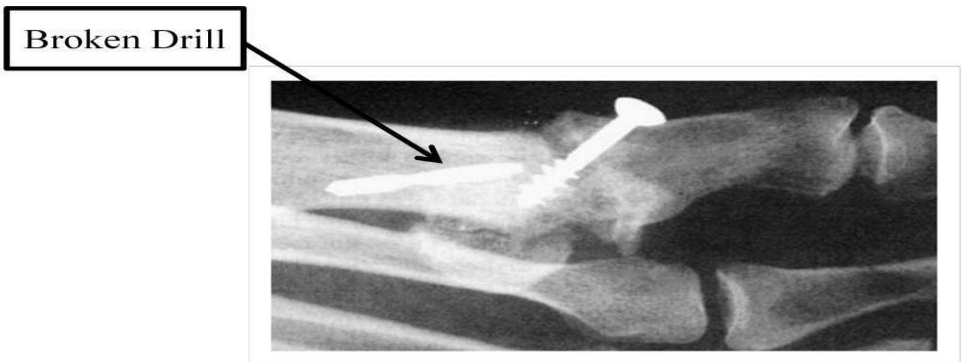


Figure 3.1: Broken drill-bit left in bone (Colin Natali, 1995)

- **Effect of Coolant**

The effect of use of coolant during bone drilling for orthopaedic surgery is investigated by many researchers. They found that cooling is one of the most important factors as it significantly decreases the temperature induced during drilling. Two methods internal and external cooling are often employed for the supply of coolant during drilling (shown in Fig. 3.2 and 3.3 respectively).

The types of cooling systems are:

1) Internal cooling system
2) External cooling system

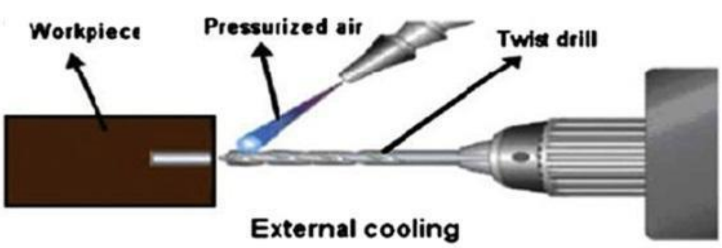


Figure 3.2: View of external cooling.

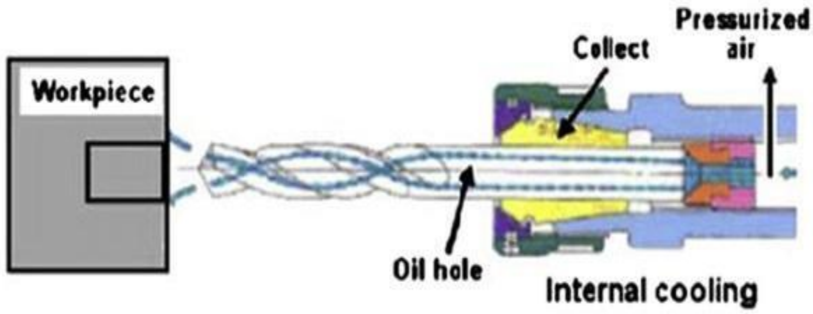


Figure 3.3: Systematic arrangement of internal cooling system.

Internal cooling involves feeding of the coolant to the drill tip through the tubules in the drill shaft whereas external cooling involves feeding the coolant to the surface of the drill at the entry point. In closed type internal cooling system, the coolant circulates through the tunnels incorporated inside the drill and back to the central heat exchanger. Cooling is achieved by the mechanism of conduction of heat from the drill to the coolant flowing through tunnels. No contact between coolant and the bone takes place. In open type internal cooling system, the coolant flows through the tunnels in the drill and exits from the opening at the drill tip, thereby taking away the heat generated during the drilling process. Besides taking away the heat by conduction, the coolant also provides lubrication and irrigation (excluding closed loop internal cooling system). Lubrication reduces the friction during drilling and hence less heat is generated. Bone produces short chips when it is dry but during orthopaedic treatment it is wet therefore the chips produced get clogged which increases the friction and raises the temperature during drilling. Irrigation causes the effective removal of chips and debris which avoids clogging of flutes during bone drilling and facilitates less heat generation.

- **Depth of Drill**

Depth of drill is also a major factor which is to be taken in account before starting the bone drilling. Heat generation during drilling is a key issue which causes some major problems in recovery of facture. Presently depth is estimated by the skilled operator but if it goes in to more depth as compared to required, it will take more time to recover than the normal. Depth of drill also depends on thickness of bone. The mean cortical thickness of the bovine (7mm-9 mm) and human cadaveric (3mm-5 mm) bone. Depth of drill is also varied with the density of bone. So there is large variation in temperature as we go in depth of the bone. So the depth is the predominant factor influencing the temperature induced during bone drilling.

- **Predrilling and Step Drilling**

Drilling can be done either in single step or multistep. In single step only one drill of required diameter is used to produce the desired hole while in multistep drilling known as predrilling, drill diameter is gradually increased from minimum to the required diameter using a number of drills. This type of drilling is also known as incremental drilling. Drill bit used in step drilling is similar to the drill bit used in general drilling. In pre-drilling, total time of drilling is increased if compared to step drilling so this type tool is preferred over pre-drilling. Drill bits used in conventional drilling and step drilling shown in Fig. 3.4.

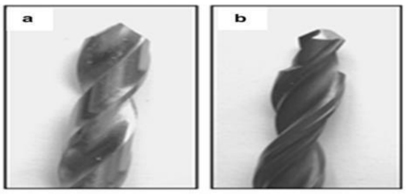


Figure 3.4: (a) Single Phase Drill (b) Two Phase Drill.

Drilling Parameters

- **Drill Bit Specification**

Any drill is usually characterized by the drill diameter, cutting face, helix angle and the drill point {Fig 3.5 (a)}. The drill cutting face is further specified by rake angle and clearance angle whereas point angle, flank and the chisel edge defines the drill point as shown in Fig 3.5 (b).

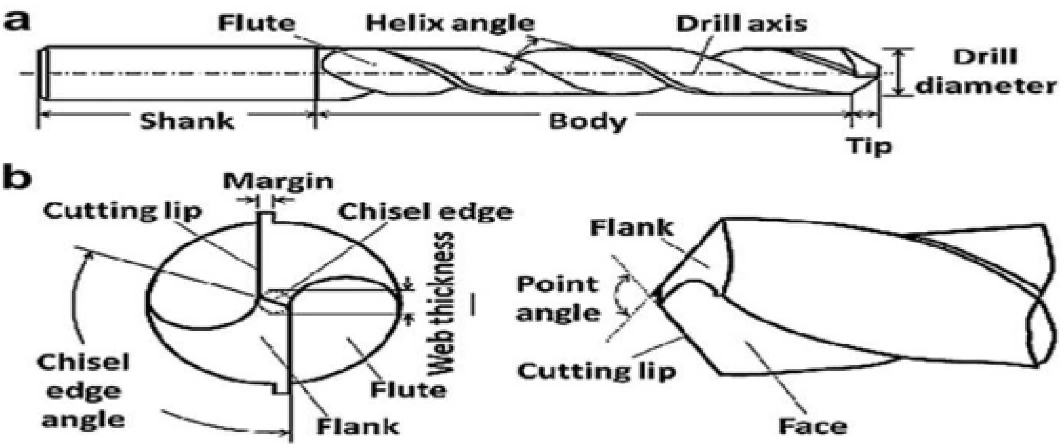


Figure 3.5: (a) Twist Drill Bit (b) Drill Bit Tip.

- **Drill Diameter**

Maximum output diameter required after drilling is the major factor, on which other parameters are to be adjusted. Generally, 2.5, 3 and 4 mm drill bits are used to drill the bone. Drill diameter is to be selected according to bone condition (density, position). Diameter of drill also affects the temperature raise during drilling. As the diameter increases, contact surface increases which results in more heat produced. But by reducing the diameter this may result in the breakage or bending of drill bit.

- **Flutes and helix angle**

The flute is a deep groove that typically twists around the drill, giving the waste material a path out of the hole. In the absence of a flute, the drill would not cut as quickly, as the waste material would need to be removed before drilling could continue. Flutes can vary in size and the drills can be constructed with number of flutes with various helix angles. Two flute and three flute drill bit is shown in Fig 3.6. No of flutes also changes the point angle, as point angle is reduced with increase in no of flutes.

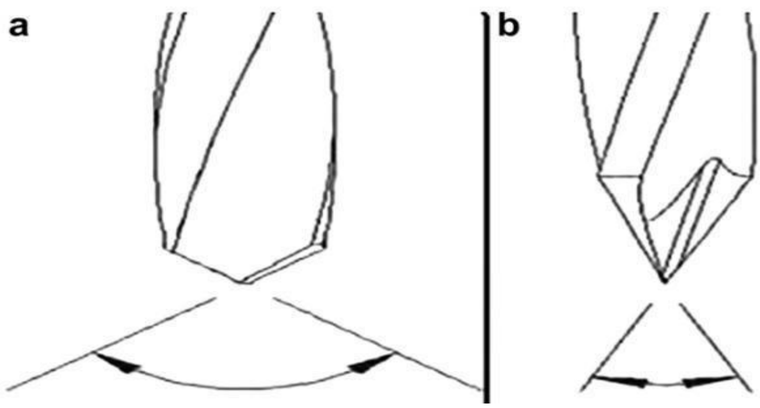


Figure 3.6: (a) Two flute (b) Three flute drill bit

- **Drill wear**

When two hard surfaces slides with each other than some part of material from the surfaces eliminate in the form of small tiny particles. In case of drilling there is wear out of cutting edges due to mechanical and thermal effect. This wear of cutting lips of drill bit may lead to the increase in axial thrust force, temperature and vibrations also.

- **Cutting Edge angles**

Front edge that involves in cutting majorly of a standard drill bit in any type of drilling includes in cutting face of drill bit. It includes:

1) Rake angle
2) Clearance angle and flank

1) Rake angle: It is the angle between the cutting edge and the plane perpendicular to the work piece. Rake angle is critically influencing the cutting forces. Several investigations have

been carried out to identify an optimal rake angle for bone drilling. An optimum rake of 20^{o}-30^{o} was recommended, as it sufficiently clears the chips and generates very low thrust force.

2) Clearance angle and flank: Flank is the flat part of the drill when viewed from end in (Fig. 1.5(b)). The flank of the drill represents a large surface area for friction during drilling. Clearance is the space provided to avoid undesirable contact of the flank with the work piece. This angle helps the flank of the drill to clears the material during drilling. Despite of the

- **Drill point**

Drill point includes two major part which helps in efficient drilling and also affect the amount of heat generation. These two parts includes:

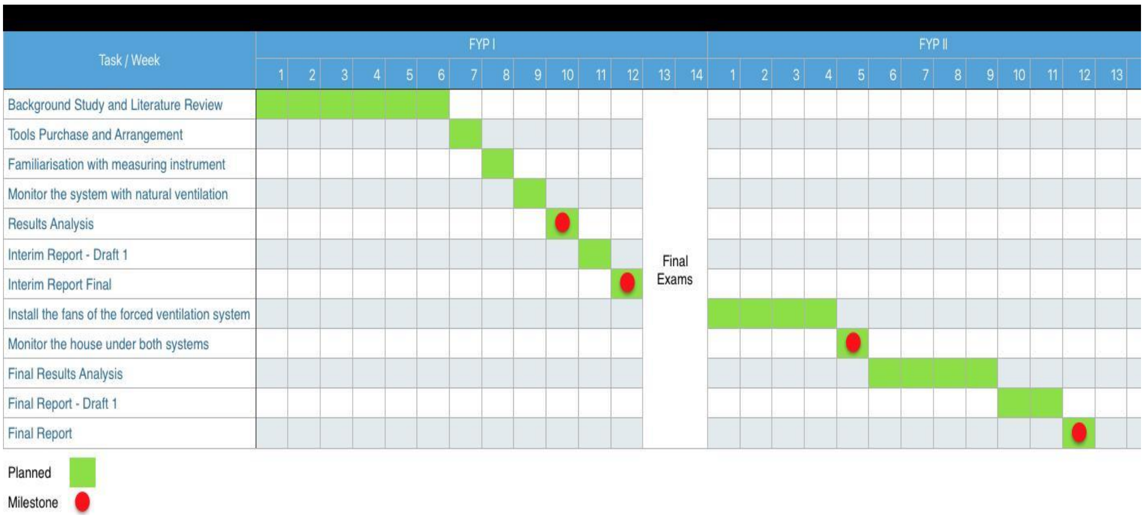
1) Point angle
2) Chisel edge

Point angle: Is the angle formed between the projections of the cutting edges on the plane passing through the longitudinal axis of the drill bit. Point angle guides the drill bit to an appropriate point where drilling is to be done. In case of bone drilling accuracy of this kind is needed as much as possible because risk cannot be taken with human on the operation table. The smaller the point angle is the more the acute tip is which can easily stab in the bone, where needed. But the problem with more acute tip is that the less portion of cutting lip will be involved during first few revolutions of drill bit and results in higher rate of raise in temperature. On the other side when large point angle is to be used then full contact of cutting lip is involved in the cutting action. Investigations, highly recommend the 90° point angle in most of cases.

Chisel edge: Is defined as the edge at the end of the web that connects the cutting lips. Length of chisel edge is equal to the web thickness and it also determines the difference between the cutting edges about the axis of rotation. Chisel edge have a direct relation with thrust force produced at the time of drill.

3.2 Gantt chart and milestones

Table 2 Project's Gantt Chart



CHAPTER 4 – EXPERIMENTATION

This chapter explains the setup of the experiment and the tools used for the process. According to the researches and the previous work, the nearest available type of bone similar to human bone is a goat bone.

A fresh bone was brought and left to soak in water for 3-4 hours to get rid of the blood left in it then the excess meat was removed with a knife to avoid smell in the labs.

Figure 4.1: Fresh goat long bone

A Bosch hand drill of 1500 RPM and 600 lb of torque was used to simulate the real conditions of surgical operations and produce similar results of those achieved in operations.

Figure 4.2: Bosch hand drill

A set of 2.5mm, 4mm and 5mm diameter metal index black oxide drill bits with a 135^o split point edge, a 2 flute drill bit and 29^o degree helix angle were used to drill the bone.

After the bone was cleaned and prepared, the bone was held in place with a clamp and the drill bits were installed in the hand drill and started drilling, it was noticeable that the 2.5mm drill bit was the fastest drill bit used to make a hole in the bone while the 5mm was the slowest. After the holes were drilled, the bone was cut into 3 small parts to be able to put them under the microscope with a manual saw then cut to a 1.5cm X 1.5cm with the grinder cutter.

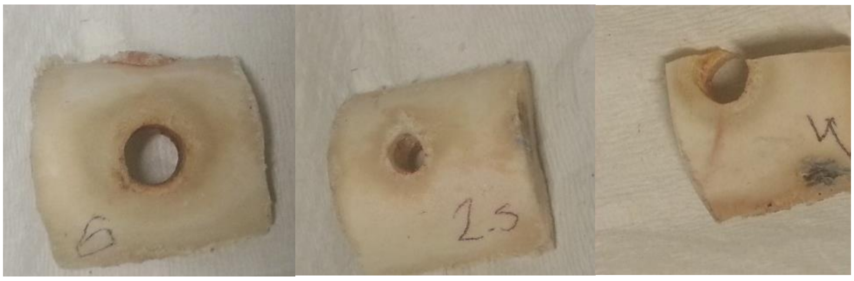


Figure 4.3: 5mm, 2.5mm and 4mm drilled specimens

These specimens were then put under the microscope to test the effect of every drill bit on the surface integrity and the quality of the hole first before cutting them again to be able to test the surface roughness of every drill bit.

Figure 4.4: Specimens were cut in half to test surface roughness

Chapter 5 – Results and Discussion

Using the Phenom Pro X microscope, the specimens were tested and the following results showed up.

- **2.5mm Φ specimen:**

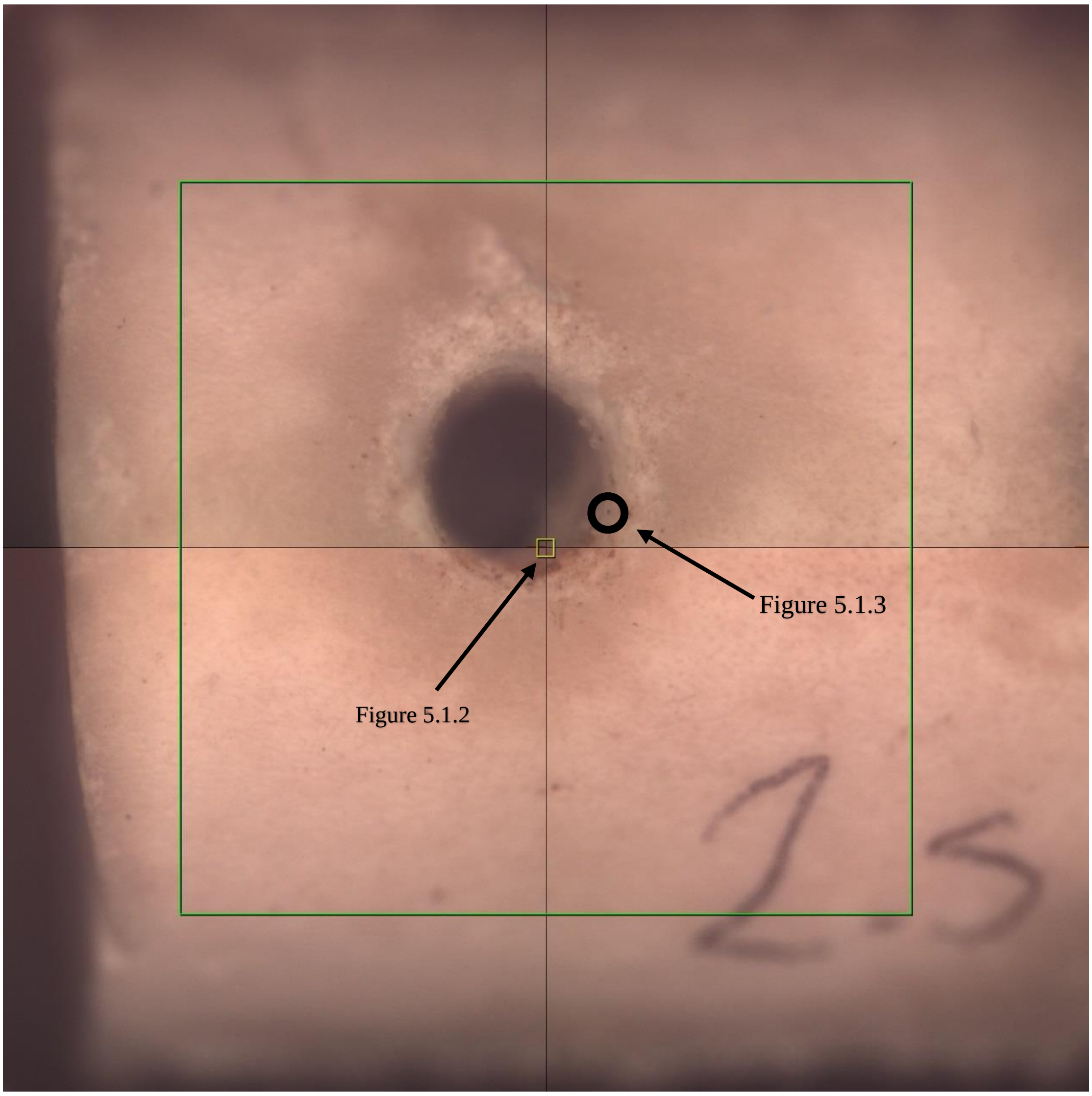


Figure 5.1: 2.5mm Φ top view before zooming

Figure 5.1 shows the 2.5mm Φ specimen under the microscope before zooming and shows the places of were figures 5.1.2 and 5.1.3 occur on the specimen.

Figure 5.1.2: 2.5mm Φ top view 500x zoom

Figure 5.1.2 shows that there are micro cracks and a lot of fragments of bone extruding from the surface which indicates that the surface is damaged but those extrusions are considered milled extrusions compared to the size of the hole.

Figure 5.1.3: 2.5mm Φ top of the hole 500x zoom

Figure 5.1.3 shows the top of the hole and how the drill bit has affected it, it shows that the 2.5mm drill bit has caused a lot of mini-fractures but the quality of the hole is still good and in line with the curved red line showing.

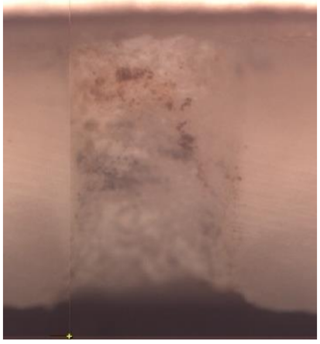
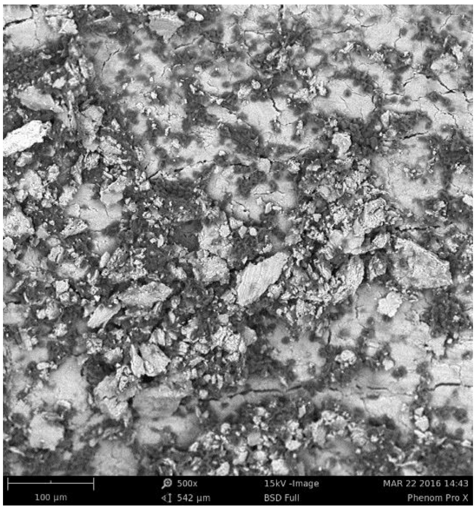


Figure 5.1.4: The inside of the 2.5mm Φ hole



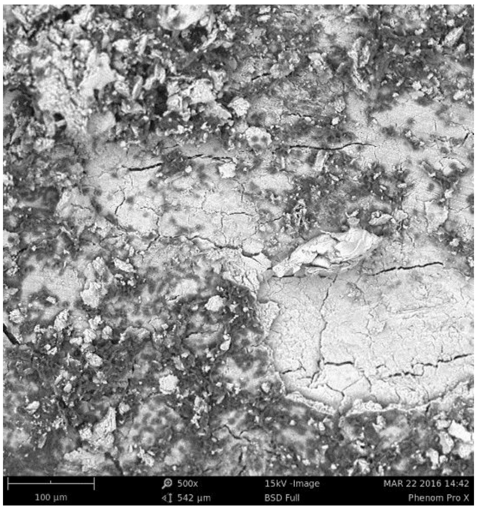
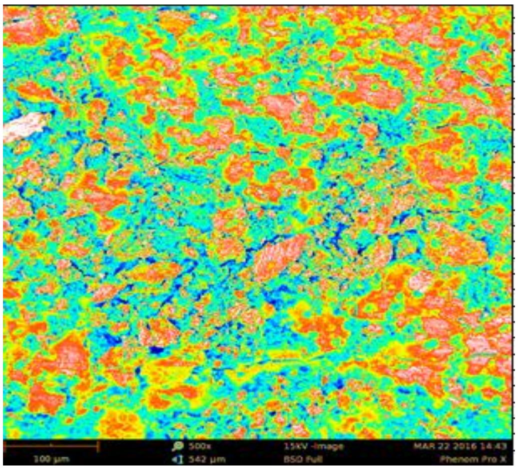


Figure 5.1.4 (a): SEM 1 of 2.5mm Φ hole Figure 5.1.4 (b): SEM 2 of 2.5mm Φ hole



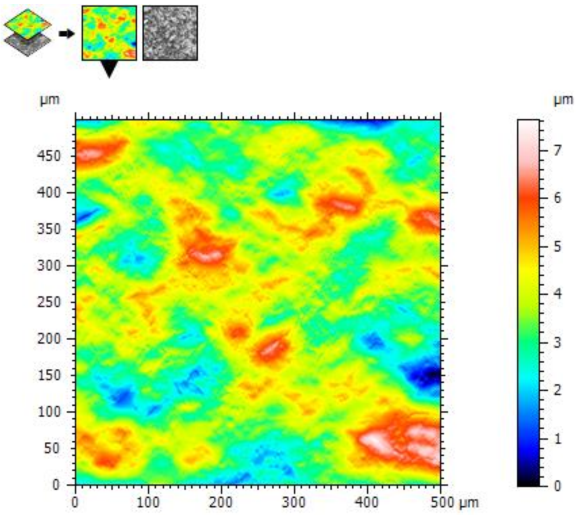


Figure 5.1.4 (c): Analysis of figure (a)   Figure 5.1.4 (d): Analysis of figure (b)

Figures 5.1.4 (a) & (b) are the results from the SEM microscope while (c) & (d) are results of (a) & (b) being analyzed using Mountains Map software which shows the SEM images in heights and anomalies form to be able to see the surface roughness and noise. Figure 5.1.4 (d) shows that the surface of the drill is mostly smooth but have some points above the average and other below the average height of the surface considering that 2.5µm – 3.5µm is the average height of the surface in figure 5.1.4 (b). While figure 5.1.4 (c) shows that there is a lot noise on the surface of figure 5.1.4 (a) which indicates that the surface is not smooth, which supports the other half of the analysis.

- **4mm Φ specimen:**

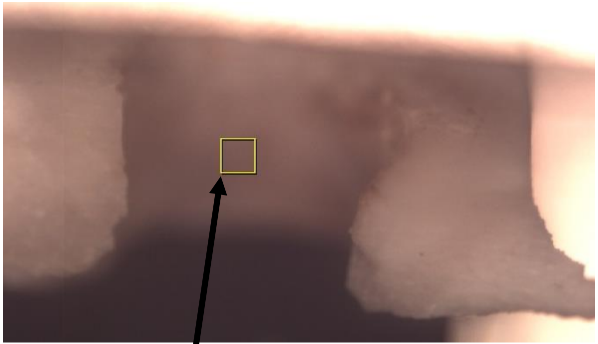


Figure 5.2.1: The inside of the 4mm Φ hole

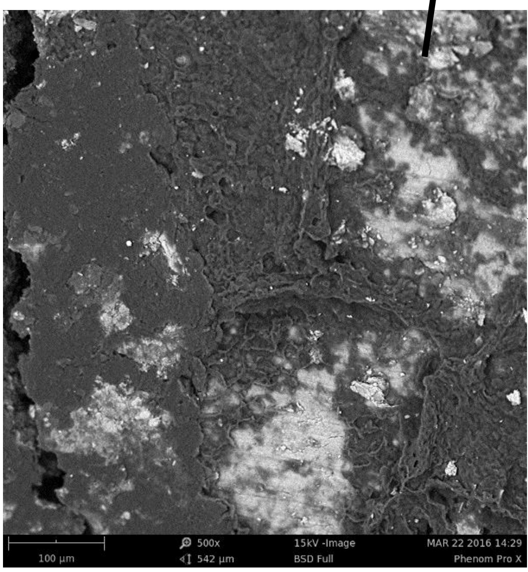


Figure 5.2.2 (a) SEM of the 4mm Φ hole

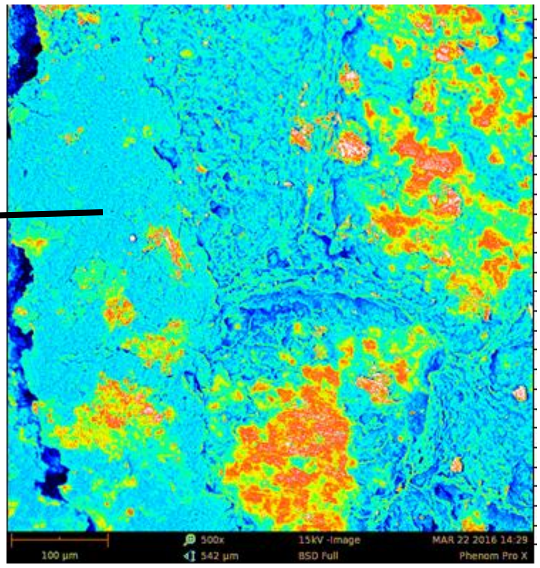


Figure 5.2.2 (b) Analysis of figure (a)

Figure 5.2.2 (a) shows that there is a big crack taking almost the whole image on the left side but the rest of the surface is almost crack free. Figure 5.2.2 (b) shows that there are some anomalies on the surface but not as much as in figure 5.1.4 (c) making the surface of the drill almost smooth.

- **5mm Φ specimen:**

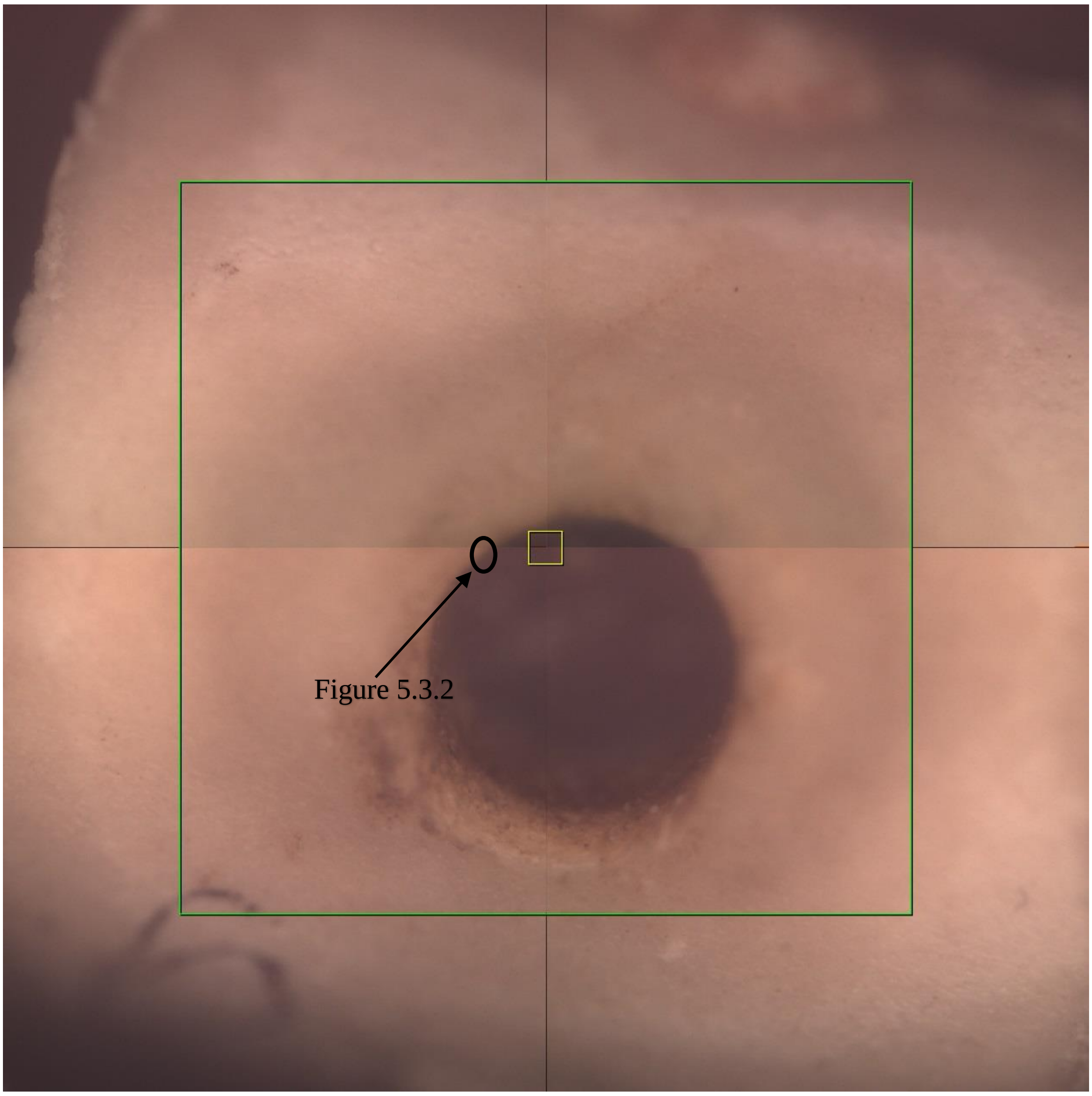


Figure 5.3.1: 5mm Φ top view

Figure 5.3.1 shows the top of the hole and indicate where did the zooming in took process to test the specimen.

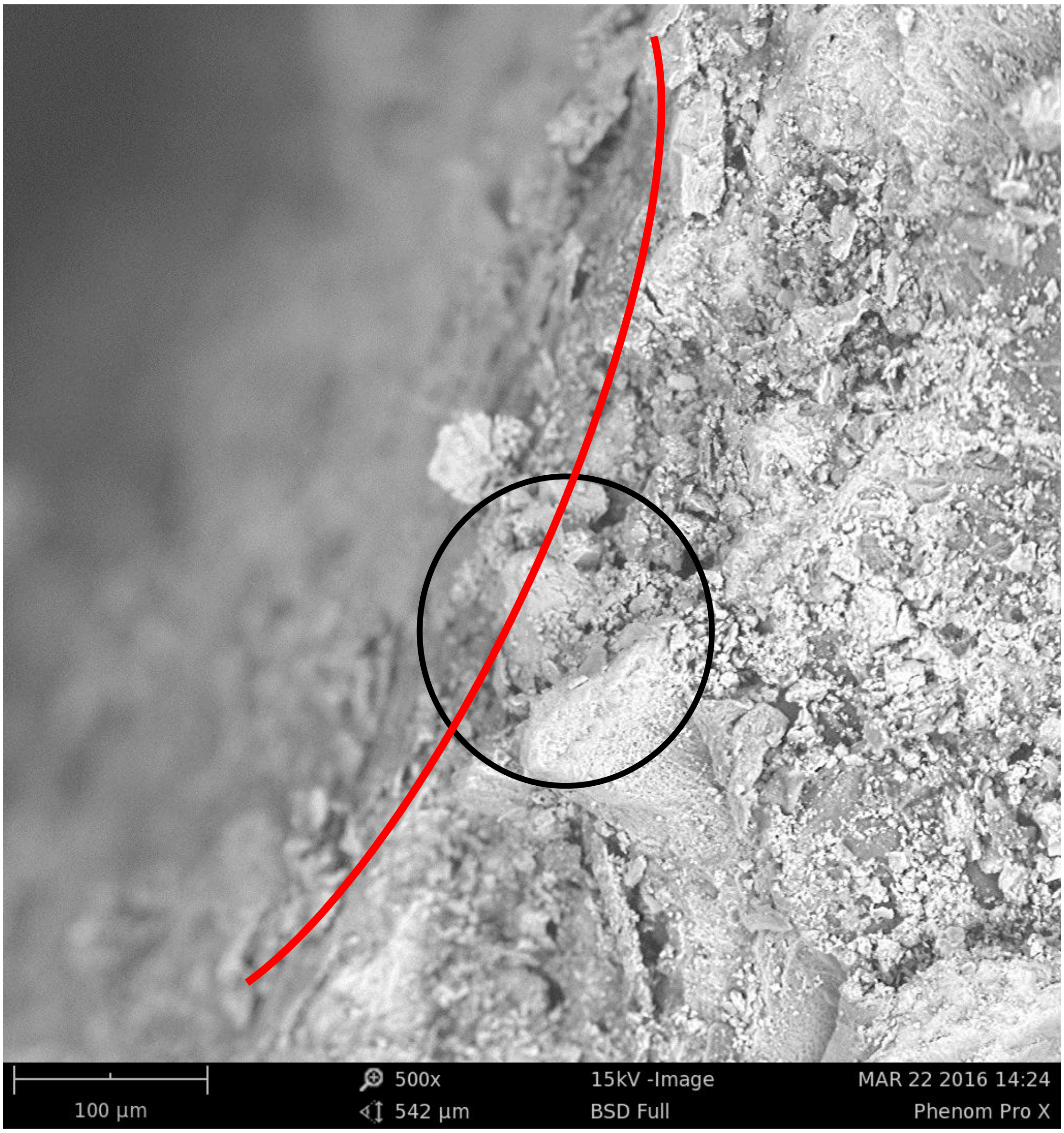


Figure 5.3.2: Top of hole 500x zoom

Figure 5.3.2 shows the edge of the hole from top view, the figure shows that the 5mm drill bit has caused a lot of damage to the holes' edge where large chunks of bone are missing from the edge, highlighted by the black circle, while the inside of the hole is still in line with the curved red indicator.

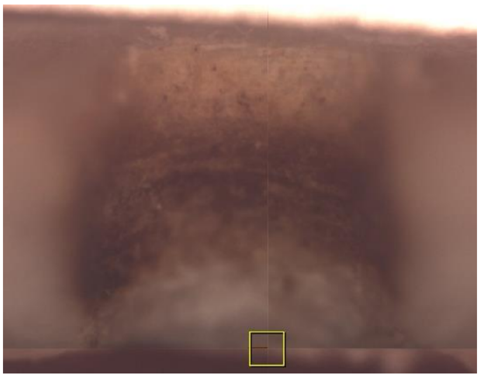


Figure 5.3.3: The inside of the 5mm Φ hole

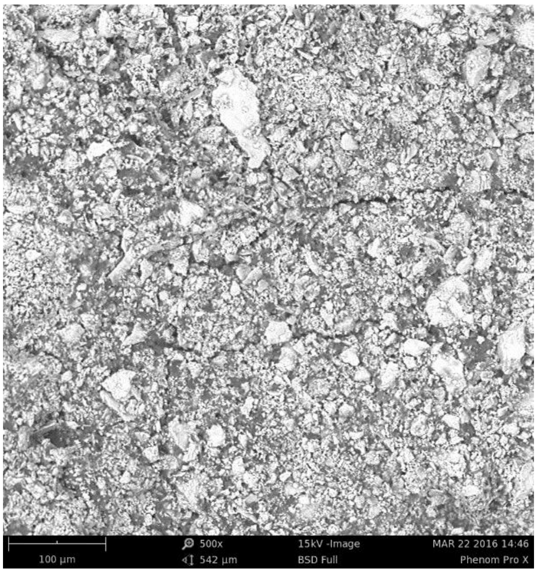


Figure 5.3.3 (a): SEM 1 of 5mm Φ hole

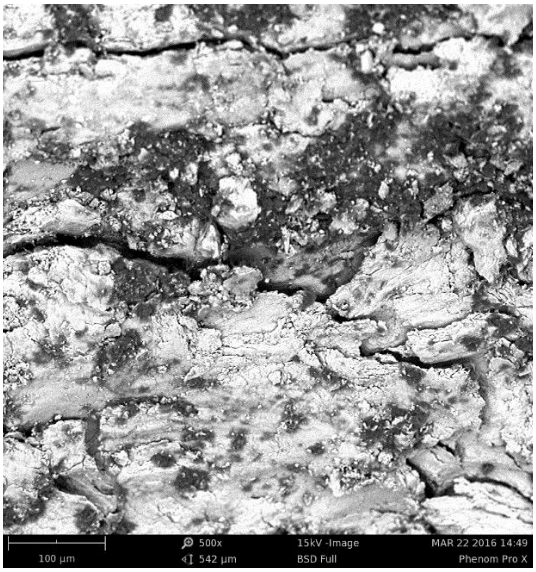


Figure 5.3.3 (b): SEM 2 of 5mm Φ hole

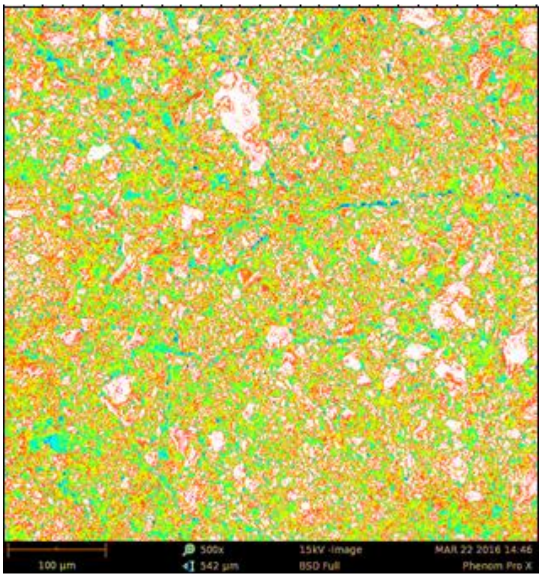


Figure 5.3.3 (c): Analysis of figure (a)

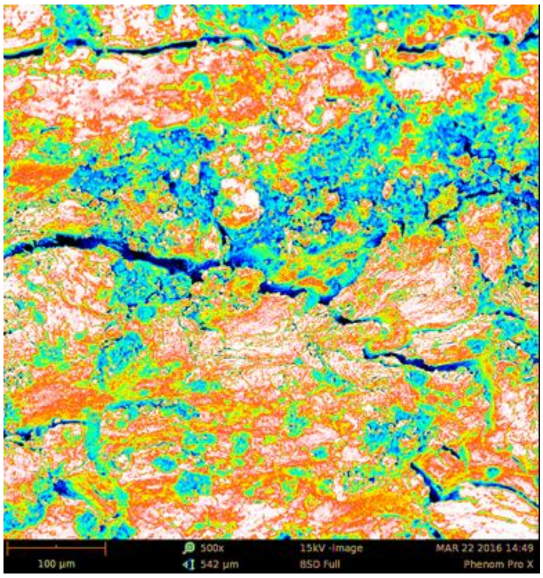


Figure 5.3.3 (d): Analysis of figure (b)

Figure 5.3.3 (c) shows a lot of red and pale red spots which indicates that there is an enormous amount of noise on the surface of the hole while figure 5.3.3 (d) shows clearly the large cracks in the surface and how that the extrusions exceed the height of 7µm which means that this is not a smooth surface.

CHAPTER 6 – CONCLUSION

The conclusion of this investigation is drawn from the previous chapter and the findings of the several tests done on the specimens.

- Surface integrity:
  Based on the SEM images and analysis, the best surface integrity is the one of the 2.5mm Φ hole, while the 4mm Φ hole also has a good surface but the appearance of large scale cracks makes the 2.5mm Φ hole better.
- Surface finish:
  Based on the topography images and the mountains map software analysis, the 4mm Φ hole has the best surface finish as there was very little noise and extrusions on its surface.
- Surface roughness:
  Based on both the SEM and the Topography data, the 4mm Φ hole has the best surface roughness with a small amount of extrusions not exceeding the height of 6µm.

Therefore, the best drill bit diameter used according to the objectives is the 4mm Φ drill bit.

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