

**Effect of diamond-like carbon coating on implant drill wear  
during implant site preparation**



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# Effect of diamond-like carbon coating on implant drill wear during Implant site preparation

## Key words

Diamond-like carbon

Drill wear

Dental implants

Drilling time

Drill design

Scanning electron microscopy

Stainless steel drill



## Definitions

**Drilling:** the action of preparing an implant osteotomy using a specific dental implant drill bit.

**Drilling time:** The time taken to prepare an implant osteotomy, in this case using a single implant drill bit

**Drilling sequence:** The order of the drilling exercise from one to twenty.

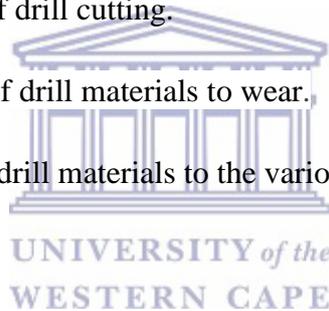
**Drilling sessions:** Drilling was carried out in 4 intervals, comprising of five drilling procedures per session.

**Drill wear:** the gradual failure or damage of drill due to regular operation.

**Cutting efficiency:** proficiency of drill cutting.

**Wear resistance:** the resistance of drill materials to wear.

**Drill hardness:** the resistance of drill materials to the various forces during drill procedure.



## Abstract

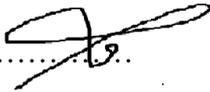
Dental implants are artificial fixtures that are surgically inserted into the jaws to replace missing teeth. The success of dental implant treatment is dependent on achieving successful osseointegration (Branemark *et al.* 2001). Drills used for implant site preparation are made of different materials such as stainless steel (SS), zirconia and ceramic. Most of them do not have sufficient cutting efficiency and wear resistance (Oliveira *et al.* 2012). Recently diamond-like carbon coating (DLC) has been added as a drill coating to increase the cutting efficiency, increase wear resistance and drill hardness (Batista Mends *et al.* 2014). **Aim:** To determine the impact of DLC coating on implant drill wear during implant site preparation. **Materials and methods:** Twenty artificial bone models were used to standardize the bone density and quality. The implant drill was attached to a surgical implant hand piece and motor. This was fitted to a drill press with a mechanical arm to allow for vertical movement and was operated by a single operator. Drills were divided into 5 groups based on manufacturer type and all implant drills were used 20 times to a drilling depth of 10mm. Isotonic saline was used as external irrigation to reduce heat generation during the drilling procedure. Drill time was recorded after 5, 10, 15, and 20 drills with a digital stopwatch. SEM images were taken of the new/unused bur before and after 0, 5, 10, 15 and 20 perforations to assess the geometric features and chisel integrity of drills. **Results:** Except for Champions Implant SS drills, no significant difference in drilling time was detected between the different drill types. SEM images showed signs of wear on all the drills, while coating delamination was detected in DLC coating drills. **Conclusion:** There was no significant difference in drilling time between DLC coated and SS drills after being used up to 20 times. In the SEM images, all implant drills from groups G1, G2, G3, and G5 revealed signs of wear after 20 uses. Champions implants drills were excluded from comparison as the manufacture recommended a drill speed of 250 rpm and maximum drill use of five times.

## Declaration

I hereby declare that “Effect of diamond-like carbon coating on implant drill wear during implant site preparation” is my own work that it has not been submitted for any degree or examination in any other university, and all that sources I have used or quoted have been indicated and acknowledged by complete references.

Marwa A.EL-Mehde Aborass

July 2017

Sign.....



## ACKNOWLEDGMENTS

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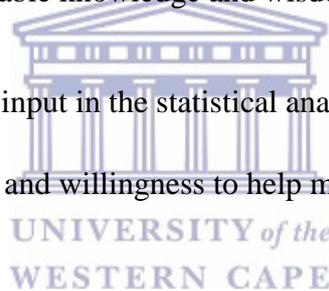
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## **Dedication**

To my loving parents,

My dear husband,

My beloved daughters,

And my dear friends

For their love, patience and support.



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## ABBREVIATIONS

DLC: Diamond-like carbon.

Sp: Spectra.

RE: Renewable energy.

DC: Direct-current discharge.

SS: Stainless steel.

TiN: Titanium nitride.

G: Group.

Rpm: Revolution per minute.

S.E: Standard error.



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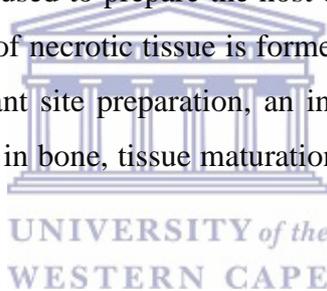


# CHAPTER 1

## Introduction

Dental implants are artificial fixtures that are surgically inserted into the jaws to replace missing teeth. They integrate with the host's bone through a process known as osseointegration. They support dental prostheses such as bridges, crowns, and dentures. The success of dental implant treatment is dependent on achieving successful osseointegration (Branemark *et al.* 2001). The latter is influenced by factors such as trauma during dental implant site preparation, and thereby affects the long-term predictability of the implant (Querozet *al.* 2008).

Specific dental implant drills are used to prepare the host bone for implant insertion. During this drilling process, a thin layer of necrotic tissue is formed in the osteotomy site. If drilling trauma is excessive during implant site preparation, an increased thickness of this necrotic layer is seen, causing a reduction in bone, tissue maturation and resulting in possible implant failure (Ercoli 2004).



## CHAPTER 2

### LITERATURE REVIEW

#### 2.1.1 Osseointegration:

Osseointegration was initially defined by Branemark *et al.* (1969) as “a direct functional and structural connection between living bone and the surface of a load carrying implant”. Zarb and Alberktsson (1991) suggested that osseointegration was “a process whereby clinically asymptomatic rigid fixation of alloplastic materials is achieved and maintained in bone during functional loading”. To facilitate the desired conditions for osseointegration or functional ankylosis, the initial fixation should be inserted with optimal stability. This optimal stability, also known as primary stability, occurs as a result of the union or friction produced between mineralized bone (mostly the cortical bone) at the recipient site and the metal device (Lindhe *et al.* 2015).

At the time of dental implant placement, the surface is covered with proteins from the patient’s blood, the first step leading to osseointegration. Implant surfaces are either coated with biomaterials, such as hydroxyapatite to encourage faster healing (Male 2015), or have rough surfaces, which provide a higher surface area for formation of the mineralized bone matrix and bone integration (Male 2015). Adequate nutrient supply is essential for osseointegration. These nutrients are transported to the osteotomy site via the blood supply of the surrounding alveolar bone. A decrease in blood supply, certain medical conditions and patient lifestyle factors, influences the healing process and thereby osseointegration. Bone type in the implant site, is another important factor to consider. Denser bone offers greater primary stability of the implant, but has less vascularity, which may compromise the healing process (Male 2015).

### **2.1.2 Dental implant installation and healing:**

Implant installation is a multistep process. These include an incision of the mucosa, the use of sequential implant drills to prepare the site, followed by insertion of the implant device into the prepared site. The response of the host tissue to this injury is that of inflammation, with the aim of removing the damaged tissue in preparation for repair or regeneration (Lindhe *et al.* 2015). In such situation, where the inserted implant is wider than the prepared osteotomy in the host bone, the mineralized bone tissue around the implant is compressed and exhibits a series of micro-fractures. In the cortical part of the canal, the blood vessels collapse, leading to a compromised blood supply and reduced nutrition. In many cases, the bone in this area becomes non-vital (Lindhe *et al.* 2015).

After implant installation, the healing of the severed bone is complex and involves various events in different compartments of the surgical site (Lindhe *et al.* 2015). In the cortical bone region, the non-vital mineralized tissue is removed before formation of the new bone. In the spongy bone marrow, injury results in localized bleeding and clot formation, which is gradually resorbed and replaced by granulation tissue. The continuous migration of mesenchymal cells from the surrounding marrow results in the granulation tissue being replaced with provisional connective tissue (provisional matrix) and finally with osteoid. Eventually, deposits of hydroxyapatite crystals in the osteoid occur in the collagen network around the newly formed vascular structures, paving the way for bone mineralization and eventual maturation (Lindhe *et al.* 2015).

### **2.2. Factors affecting heat generation during implant site drilling:**

There is an increase in heat generation during the drilling procedure associated with implant site preparation, which affects bone metabolism. An increase in temperature above 47°C for 1 minute of drilling time leads to a decrease in bone regeneration ( Eriksson and Albrektsson 1983) . Several factors influences heat generation during the drilling procedure and can lead to an increase in tissue destruction as well as implant failure. These include cortical bone thickness, pressure, cutting motion, and irrigation, drilling time, drill speed, shape and diameter of drills (Oh *et al.* 2011). A dental drill used more than once can affect its cutting efficiency (Ercoli *et al.* 2004).

## **2.2.1 Factors related to the operator:**

### **2.2.1.1. Pressure/force applied to the drill:**

Frictional heat generation is produced because of the amount of pressure the operator places on the hand piece during implant site preparation (Matthews and Hirsch 1972). Brisman (1996) reported similar findings using bovine femoral bone and showed that when a greater force was placed on the hand piece at a constant speed of 1,800 rpm, greater heat generation occurred. He concluded that the force applied to the hand piece was more influential than the speed of the drill on the drilling temperature. Eriksson and Adell (1986) recommended the use of low hand pressure, the exact value of which was not specified (Brisman 1996). In addition, is difficult to standardize between operators (Hobkirk and Rusiniak 1979).

### **2.2.1.2 Drilling speed:**

Many studies have evaluated the role of drilling speed on bone healing (Pal and Saha 1981; Boyne 1966), with no consensus. It has been shown that different speeds, when evaluated in dogs and rabbits, did not significantly affect healing and bone repair (Agren and Arwill 1968; Boyne 1966). Eriksson and Adell (1986) recommended a high-torque using a low-speed hand piece running between 1,500 and 2,000 rpm (which lead to minimal temperature rise and adequate drilling accuracy), as the ideal instruments for implant bed preparation, cited in (Tehemar 1999).

### **2.2.1.3. Drilling time:**

The drilling time influences the amount of frictional heat generated between the drill and the surrounding bone. The long-term effect of heating bone to 47°C for 5 minutes is bone resorption, associated with an invasion of fat cells and reduced osteogenic activity (Eriksson & Alberktsson 1983). A number of studies using high-speed rotary instruments have demonstrated that a decrease in drilling time will variably decrease the rise in temperature, when used with high-speed drills (Tehemar 1999; Rafel 1962). Cordioli and Majzoub (1997) concluded that the depth of the cavity, diameter and the flute geometry of the drill contributed to the required time for the maximum temperature to return to normal. However, further investigations are required to support this hypothesis.

#### **2.2.1.4. Drilling status:**

Osteotomy site preparation can be done either in one-step or in incrementally using multiple drills. Alberktsson (1980) recommended one-step drilling for screw type implant placement. However, graduated drilling has been recommended by the Scandinavian Osseointegration group. They were observed that this procedure lead to removal of a small amount of cortical bone as long as the site has been cut by a preceding bur in the series. (Eriksson *et al.* 1984; Branemark 1983). As a result, an *in vivo* study on human and animal models confirmed these results (Eriksson and Adell 1986).

#### **2.2.2. Manufacturer-Related Factors:**

##### **2.2.2.1. Drill design and flute geometry:**

Because the recipient bony bed should be of a similar diameter and shape to the proposed implant, the drill designs commonly follow the morphologic and topographic skeleton of the proposed implant. With the great variety of dental systems commercially available, comparing different drill designs and shapes are difficult. In general, twisted drills and taps are used to prepare sites for screw-shaped implants, and triflute drills are used to prepare sites for cylindrical implants ( Kay *et al.* 1991).

Several studies have established that flute geometry and drill design contributes to an increase in temperature during drilling procedure (Matthews and Hirsch 1972; Wiggins and Malkin 1978). Results also indicate that regardless of the cavity depth, a 4mm diameter triflute drill generates less heat than a 2 and 3mm twist drill or a 3,3 mm triflute drill (Cordioli and Majzoub 1997). These findings may be influenced by different materials of the models and the load or pressure applied during drilling (Watanabe *et al.* 1992; Eriksson and Adell 1986). Clinical studies have failed to identify the difference between the two designs, cited in (Tehemar 1999).

#### **2.2.2.2. Irrigation system:**

There are two kinds of irrigation systems used to decrease heat production during the drilling process: internal and external. Yacker and Klein (1996) established that without irrigation, a temperature above the threshold level is reached. An internal cooling system has several advantages as compared to external irrigation. It prevents clogging of the drill flutes by bone chips and its efficacy is constant regardless of the cavity depth (Kirschner & Meyer 1975; Koch 1976). The addition of an external cooling appears to supplement the internal cooling system (Haider 1993).

#### **2.2.2.3. Drill sharpness:**

Drill conditions play an important role in regulating the temperature of bone during the drilling procedure. Worn drills have shown to record much higher temperatures as compared to new drills (Matthews and Hirsch 1972). Several studies analysed the factors affecting drill wear and sharpness. These indicate that drill wear was related to the number of uses, pressure, sterilization techniques, density of the bone sites, construction material and drill surface treatment (Andrienne *et al.* 1987; Yacker & Klein 1996). Previous studies used scanning electron microscopy to analyse drill wear after 12 to 18 drilling procedures. It was shown that most drills were subjected to tangible wear on the cutting edges and therefore, the manufacturer's recommendations with regard to the number of times a drill may be used, must be adhered to (Sutter *et al.* 1992) cited in (Tehemar 1999).

#### **2.2.2.4. Drill diameter:**

Cordioli and Majzoub (1997) reported that less heat was generated when larger diameter drills were used compared to drills with a smaller diameter. It has also been shown that the required time for the temperature to return to normal was twice as long for a 2-mm drill compared to 3.3- mm diameter drills (Tehemar 1999). Yacker and Klein (1996) showed that the amount of bone cutting by the 3-mm drill was less than that of the previous drill (2 mm). This may explain the reduced heat generated when using a larger diameter drill. (Yacker & Klein 1996). Comparable results were described by Watanabe *et al.* (1992). Thus, it appears that amount of heat generated is influenced by the amount of bone removed rather than the drill diameter (Watanabe *et al.* 1992).

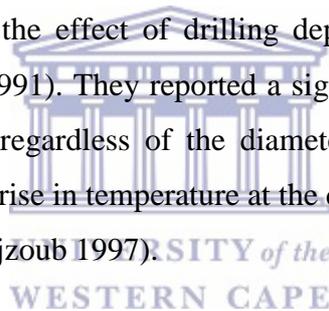
### **2.2.3. Factor related to the recipient site:**

#### **2.2.3.1. Cortical Bone versus Cancellous Bone:**

Bone engagement at the implant site is necessary for implant stabilization. Depending on implant design, this engagement may occur primarily in the cortical or cancellous bone. This has implications for healing, since it has been established that the revascularization of cancellous bone is better than that of cortical bone after surgical injury (Alberktsson 1980) whereas cortical bone is better for initial implant stabilization is better in cortical bone, mainly in the early stages of healing. (Haider 1993).

#### **2.2.3.2. Drilling Depth:**

Many studies have investigated the effect of drilling depth and frictional heat generation (Haider *et al.* 1993., Kay *et al.* 1991). They reported a significant increase in temperature at depths of 8 mm versus 4 mm, regardless of the diameter of the drill used. The type of irrigation used greatly affects the rise in temperature at the deepest level, rather than the depth of the site itself (Cordioli and Majzoub 1997).



#### **2.2.3.3. Healed Versus Healing Site:**

Placement of dental implants in fresh extraction sites might lead to reduced treatment time and take advantage of the reparative process of the extraction socket. Some authors maintain that less heat was generated during implant drilling in a healing site than in a healed site (Gher *et al.* 1994; Meffert 1997). An extraction socket is usually larger in diameter than that of the proposed future implant because of the expansion phenomenon associated with the extraction procedure. Thus, the drill usually only engages the apical portion of the socket, which can markedly reduce the amount of frictional heat (Tehemar 1999).

## **2.2.4. Factors Related to the Patient:**

### **2.2.4.1. Age**

In old patients, several physiological changes occur. Bony structures tend to become more fragile, with rapid enlargement of the medullary cavity spaces. This leads to a reduction in cortical thickness, mass and impaired healing capability (Holden *et al.* 1995). In addition, bone aging is characterized by a greater increase in crystalline structure of the bone mineral matrix; corresponding to size increase and enhancement in the chemical arrangement composition of the apatite crystals of bone matrix (Holden *et al.* 1995; Legros *et al.* 1987).

### **2.2.3.2. Bone density and texture:**

Bone density is never the same in two people, nor do we find the exact density in the same skeleton as well as in the same bone. With regards to the effect of density on the temperature generated, Yacker and Klein (1996) established that bone density is a good indicator of bur temperature rather than the osteotomy depth. An in vitro study on bovine bone blocks found a significant difference in temperature between cortical and cancellous bone, regardless of drilling depth. Drilling depths of 8.5, 18.5, and 20.5 mm generated drill temperatures in the cortical bone of 54.0°C, 51.9°C, and 115.8°C, respectively. In cancellous bone, the temperature decreased from 49.5°C to 39.3°C even when the depth increased from 10.5 to 15.5 mm. However, further studies in human bone are needed to confirm these findings (Yacker and Klein 1996) cited in (Tehemar 1999).

## **2.3. The drills used to place implants:**

Drills used for implant preparation are made of different materials such as stainless steel (SS), zirconia and ceramic. Most of them do not have sufficient cutting efficiency and wear resistance (Oliveira *et al.* 2012). Recently diamond-like carbon (DLC) has been added as a drill coating to increase the cutting efficiency, increase wear resistance and drill hardness (Mends *et al.* 2014).

## 2.4. Definition of diamond-like carbon:

Diamond-like carbon coating (DLC) is defined as an amorphous carbon or non-crystalline structure, which has similar properties to diamonds (Lin *et al.* 2011). DLC is used as coverings for other materials, which confers the advantages of the diamond properties to the surface (Evtukh *et al.* 2001).

## 2.5. Diamond-like carbon structure:

Based on the carbon-carbon bonds, diamond like carbon is divided into two kinds: Hexagonal graphite bonds (DLC Raman Spectra  $sp^3$ ) which consist of high frequency (Graphite) band peaks of Raman Spectroscopy and Tetrahedral diamond bonds (DLC Raman Spectra  $sp^2$ ), which has a low frequency (DLC) band peak of Raman Spectroscopy. DLC can be hydrogenated or non-hydrogenated (Nine *et al.* 2014; Tarabolsi *et al.* 2013). Hydrogenated DLC is made by a hydrocarbon gas mixture that uses different energy sources such as microwave, RE energy, DC discharge and oxyacetylene torches. Non-hydrogenated DLC is formed using electron beam evaporation, laser ablation, magnetron sputtering and mass filtered carbon –ion deposition techniques (Hauret *et al.* 2013).

The hard carbon coatings have various  $Sp^3/Sp^2$  bond ratios and different physical as well and structural characteristics (David and Jonathan 1995). DLC presents in various forms, which consist of a principle amount of  $Sp^3$  hybridized carbon atoms. Additionally, the carbon atoms may be organized in a cubic, or seldom, in a hexagonal lattice (Kvzan *et al.* 2009). The irregular change in DLC between the hexagonal and cubic lattice structure of natural diamond results in a smooth and highly reflective surface of DLC (Evtukh *et al.* 2001). DLC when viewed under microscope appears similar to a cobblestoned path. When it is in pure form, it has the characteristic hardness of diamond, but is smoother than Teflon.

T tetrahedral amorphous carbon is another kind of diamond like carbon, which is harder and stronger than the hexagonal and cubic forms (Evtukh *et al.* 2001). In 2006, an authoritative report VDI2840 written by German engineers in Western Europe, proposed a different classification for DLC. They highlighted that the  $Sp^3$  bonds do not only occur between the crystals, but in amorphous solids with different orders of atoms, the bonding happen occurs between a few individual atoms. There are many types of bonds, which affect the amorphous

carbon properties. When there are more Sp<sup>2</sup> type than Sp<sup>3</sup> bonds, the amorphous carbon becomes softer. Whereas when the Sp<sup>2</sup> type bonds are less than Sp<sup>3</sup>, the carbon gets harder. Another determining factor was found to have the consist of hydrogen or methane as a catalyst. The polyethylene is produced by the carbon, which are connected to each other by the DLC Sp<sup>3</sup> bonds as well as chemical bonded hydrogen. The VDI report affirmed the different diamond like carbon bonds, which relies on the location of the two-map dimension, where the axis (X) depicts the hydrogen part of the material. The axis (Y) represents the Sp<sup>3</sup> carbon bonds.

## 2.6. Advantages of Diamond-like carbon:

There are many advantages of DLC:

- Increased hardness and elastic modulus as well as more wear resistance (Wang *et al.* 2007).
- Less friction at the cutting site - that leads to decreased tissue necrosis, improved Bone healing and high thermal stability (Franklin and Baranowska 2007).
- DLC has accurate thermal conductivity as well as biocompatibility (Wang *et al.* 2007).

These advantages allow for more precision while drilling in close proximity to vital structures.

## 2.7. Comparison between the three drill materials:

A previous study measured the effect of DLC on the drill wear compared to SS and zirconia (Mendes *et al.* 2014). The study looked at deformation, roughness and mass loss. The researchers used bovine ribs with a standard thickness of 4mm (Sumer *et al.* 2011; Yacker *et al.* 1996). The authors did not find much difference in mass and roughness between all the groups as well as subgroups tested, before and after 10,20,30,40 perforations (Sartori *et al.* 2012). However, DLC ‘coating delamination’ was noticed whereas ‘irregular surface wear’ was detected in some of the other groups (Bayerlein *et al.* 2006). In another study by Yunn-Shiuan *et al.* in (2013), the authors used three types of SS tips with various coated treatments to examine the effect of tip coating on ultrasonic devices (Cur scale, Bonart Taiwan). These included an uncoated tip, a titanium nitride (TiN) coated tip and a DLC coated tip.

The study indicated that the DLC coated tips had the highest material removal rate because of its lower coefficient of friction. Drill design, material and mechanical properties have a particular effect on cutting efficiency and wear resistance (Ercoli *et al.* 2015). The wear of drills on rabbit's tibia differ from that of drills used on bovine ribs for implant osteotomies (Carvalho *et al.* 2011). These researchers created six groups (G1 till G6) corresponding to the osteotomy number produced for every drill (10, 20, 30, 40 and 50 times) and conducted a Scanning Electron Microscope analysis. Drill deformation was positively related to an increase in the re-use of these drills (Scarano *et al.* 2007). This has the potential to result in a higher exposure to trauma and damage of the tissue (Mann *et al.* 2006). The net result of negative aspects related to the performance of these drills is an adverse influence on osseointegration, which is vital for implant success (Bonwald *et al.* 2002).

## **2.8. Conclusion:**

The current literature often investigates the wear patterns of various drill materials and focuses on the effect of temperature and mass changes associated with these materials. From the literature reviewed, there is no conclusive study that compares drill wear and drilling time, specifically for DLC coated drills. The purpose of this study is thus to investigate the wear of DLC coated implant drills during implant preparation and compare them to SS drills.

## CHAPTER 3

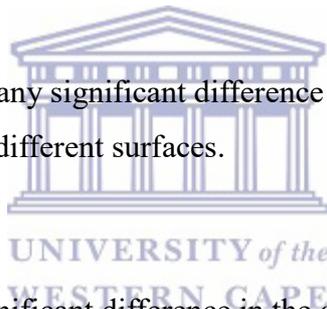
### Aim and Objectives

#### 3.1. Aim:

To determine the impact of a diamond-like carbon coating on a dental implant drill wear after implant site preparation.

#### 3.2. Objectives:

1. To determine whether there is any significant difference in the implant drilling time for implant drills manufactured with different surfaces.



2. To determine if there is any significant difference in the geometric features and chisel integrity of a diamond-like carbon coating versus stainless steel drill after repeated use.

## CHAPTER 4

### MATERIALS AND METHODS

#### 4.1. Study design:

This study was an *in vitro* laboratory based study.

#### 4.2. Sample size:

Twenty artificial bones (Straumann® Basel, Switzerland) were used to standardize the bone density and quality.



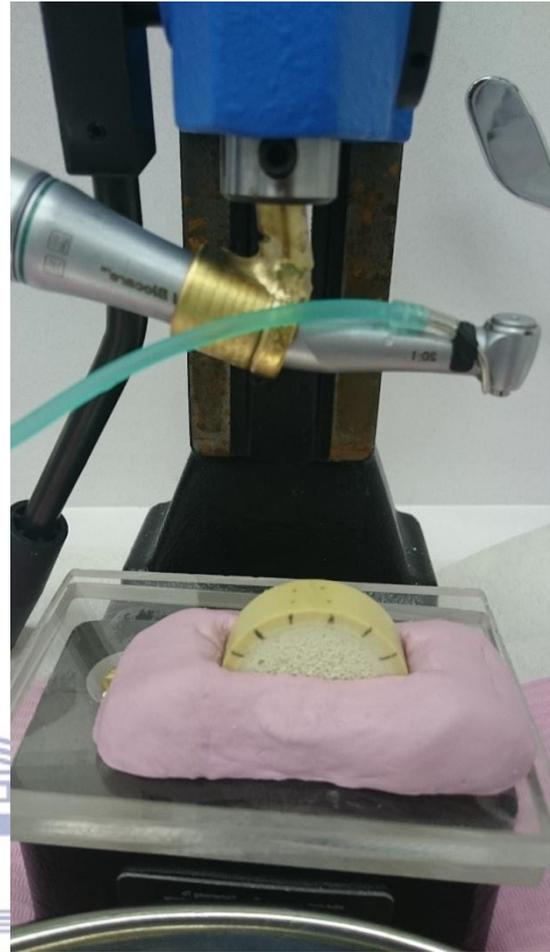
**Figure 1: Artificial bone.**

#### 4.3. Drill numbers and materials:

Thirteen pilot drills were sourced from different manufactures (stainless steel & diamond-like carbon). All the implant drills were used to a depth of 10mm (as marked on the drill surface). The implant drill was attached to a surgical implant hand piece (Nobel Biocare® W&H Dentalwerk Austria) and electrical motor. Drill speed and torque were determined by the manufacture's recommendation of sequential drilling (Osseoset 200, SI-923; Nobel Biocare® W&H Dentalwerk Austria). The surgical implant hand piece was fitted to a drill press with a mechanical arm to allow for vertical movement (MK-dent® RT2010 Germany); and operated by a single operator. All implant drills were used 20 times to 10mm drilling depth in a stable artificial bone block. Additionally, during all the preparation, isotonic saline was used as external irrigation to reduce heat generation during the drilling procedure. (Figure 2 to Figure 4).



**Figure 2: Drill press with mechanical arm.**



**Figure 3: Drill press with surgical handpiece attached and artificial bone stabilized in lab putty.**



**Figure 4: Sample of drill materials.**

#### 4.4. Drill sterilization:

After 5 perforations, all drills were rinsed with distilled water, dried using compressed air, then drills sterilized in an autoclave (Steri-vac®: gas sterilizer, 3M Medical Surgical division, Paul, U.S.A) in Tygerberg Hospital at 127°C for 40 minutes.



Figure 5: Drill rinses with distilled water & drill kit for sterilization.



Figure 6: Drills after being dried by air compression.



Figure 7: Drills kit ready for sterilization.

#### 4.5. Drill groups:

Drills were divided into 5 groups based on manufacturer type (Table1).

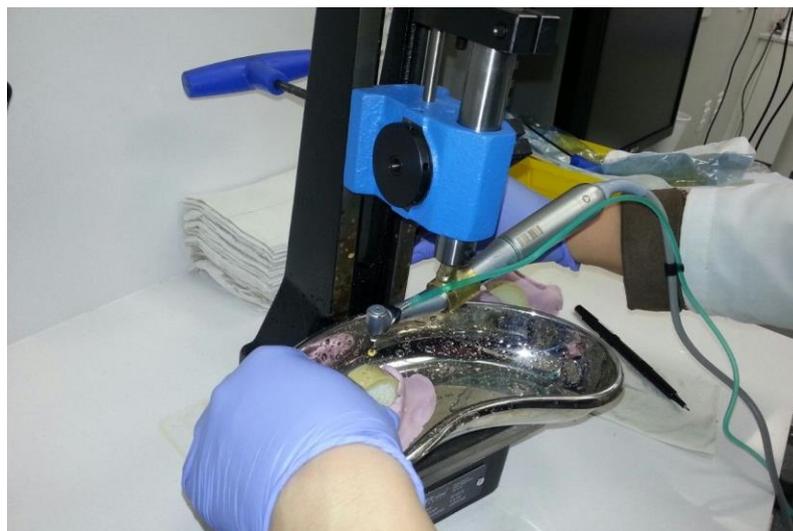
**Table 1: Drill numbers and composition.**

Group	Drill surface	Manufacture	Drill speed	Number of drills	Drill type	Drill diameter
1	Stainless steel	Adin®	800 rpm	2	Pilot drill	2mm
2	Diamond like carbon	Adin	800 rpm	3	Pilot drill	2mm
3	Stainless steel	Megagen	850 rpm	2	Pilot drill	2mm
4	Stainless steel	Straumann	800 rpm	3	Pilot drill	2mm
5	Stainless steel	Champions implants	250 rpm	3	Pilot drill	2mm

#### 4.6. Drilling time:

Drill time was recorded after 5, 10, 15, and 20 drilling with a digital stopwatch.

Drilling time i.e. the time it takes to drill to 10 mm (as marked on the drill surface) was measured after every five times the drill was used.



**Figure 8: Drilling time recorded during drilling procedure with external irrigation.**

#### 4.7. Scanning electron microscopy (SEM) analysis:

SEM (AURIGA High resolution SEM, Carl Zeiss Microscopy GmbH, Jena Germany) images were taken in unused state before and after 0, 5, 10, 15 and 20 perforations. These measurements were used to evaluate the sharpness integrity and the wear characteristic of the specimens. Photomicrographs were taken at 30X and 150 X magnifications to measure the geometric features and chisel integrity of drills.



Figure 9: Scanning electron microscopy (SEM).



Figure 10: Drills prepared for SEM analysis.

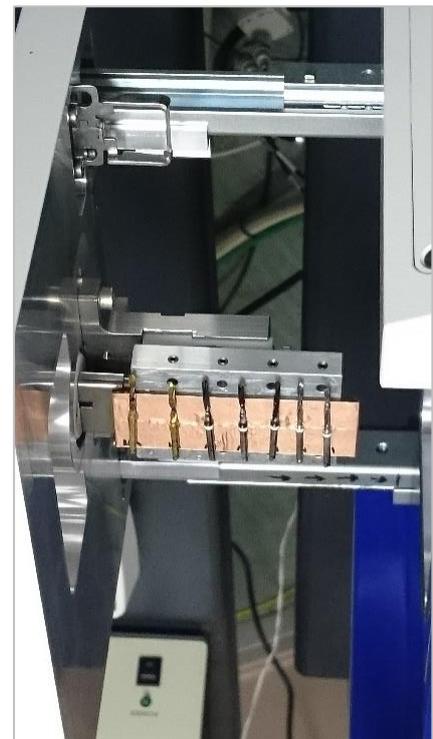


Figure11: SEM analysis for drills.

## **4.8. Data collection:**

### **4.8.1. Statistical Analysis:**

All statistical analysis was performed using SPSS statistical software Version 21 (IBM, USA) and a p value  $<0.05$  was considered statistically significant. Data collected was recorded in tables and summarized on a Microsoft® Excel spreadsheet.

### **4.8.2. Ethical Statements:**

This was an in vitro laboratory based study, and no organs or human tissue were used for the purpose of the study. The study was not supported by any research grant from any foundation nor company, and the researcher declared that there was no conflict of interest. Ethics approval was obtained from the biomedical research ethics committee – project registration number: 15/7/38.



# Chapter 5

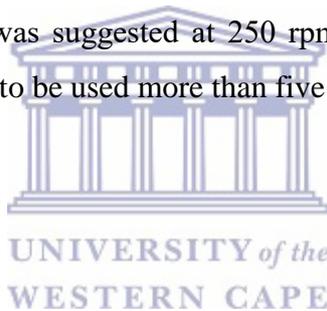
## Results

### 5.1. Drilling time results:

No significant difference in drilling time was detected in the first four groups between the diamond-like carbon and stainless steel drills.

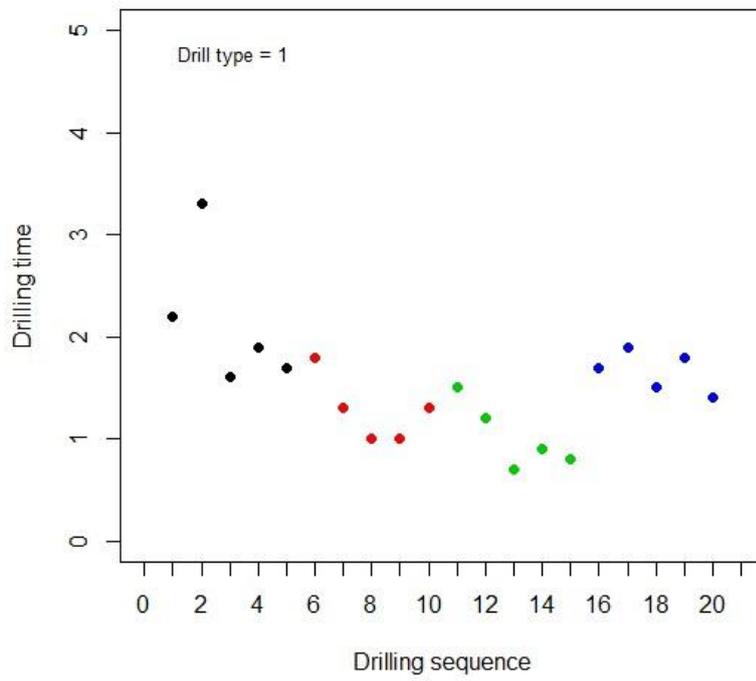
The initial three sessions showed a clear downward trend in drill times. Thereafter an upward tendency in session 4 was observed as shown in figure 12 to figure 21.

In the fifth group, the trend was in an upward direction with drilling sequences increasing as shown in figure 22 to figure 24. Group 5 could not be compared with the other groups as the recommended speed of drilling was suggested at 250 rpm. In addition, the manufacturer's instruction do not allow the drills to be used more than five times.

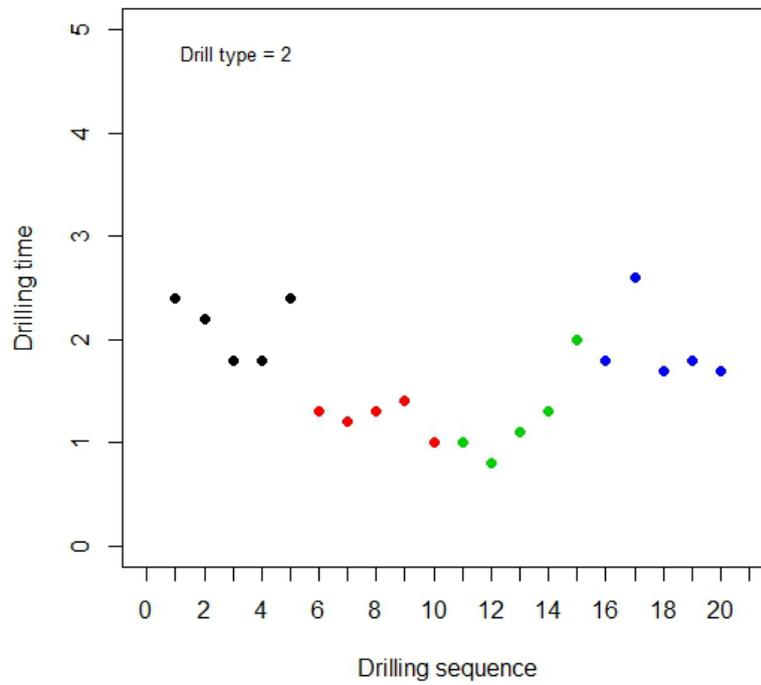


### 5.2. Breakdown of results:

**5.2.1. Group one:** Two stainless steel drills (Adin Alon Tavor POB1128, Afula, Israel) - the first drill measurement averaged 2.3 seconds after which a decrease in time to approximately 0.7 seconds was recorded at the 13<sup>th</sup> drilling. Thereafter the time taken to reach the desired depth increased and with the final attempts recording around 2 seconds. (Refer to Figures 12 and 13).

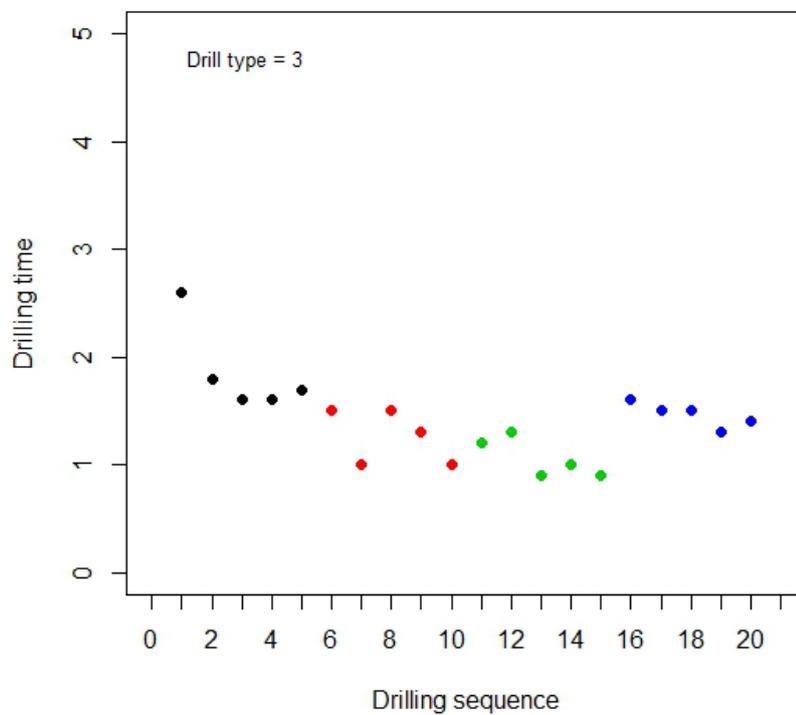


**Figure 12: Group1 (SS) drill type 1.**

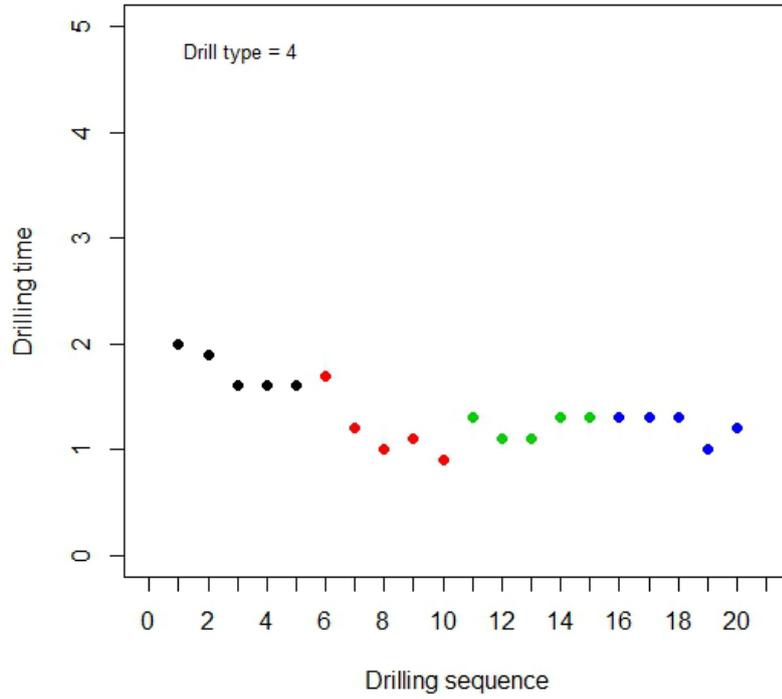


**Figure 13: Group 1 (SS) drill type 2.**

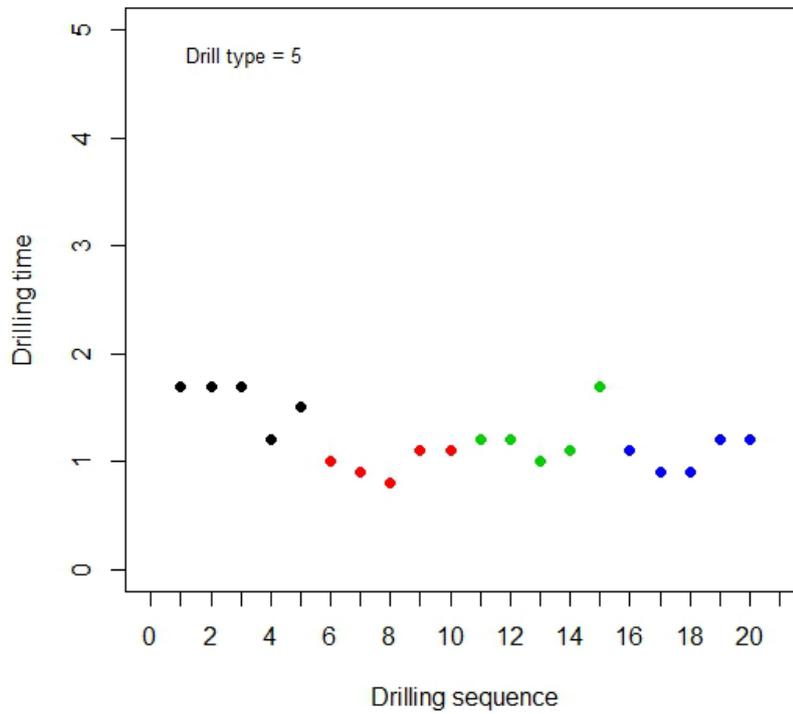
**5.2.2. Group two:** Three diamond-like carbon drills (Adin Alon Tavor POB1128, Afula, Israel) -the first drill measurements averaged 2.15 seconds whereafter the speed reduced to an average of 1.1 seconds from the 7<sup>th</sup> drilling, while maintaining this average onwards to drilling 15. The rest of the exercise showed a steady but miniscule increase in drill times to an average of 1.3 seconds. (Refer to Figure 14, 15, and 16).



**Figure 14: Group 2 (DLC) drill type 3.**

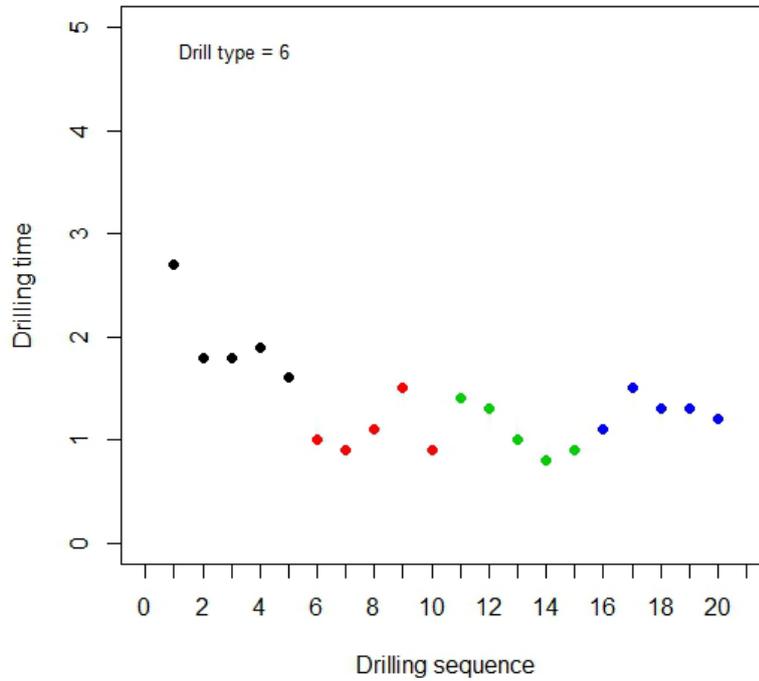


**Figure 15: Group 2 (DLC) drill type 4.**

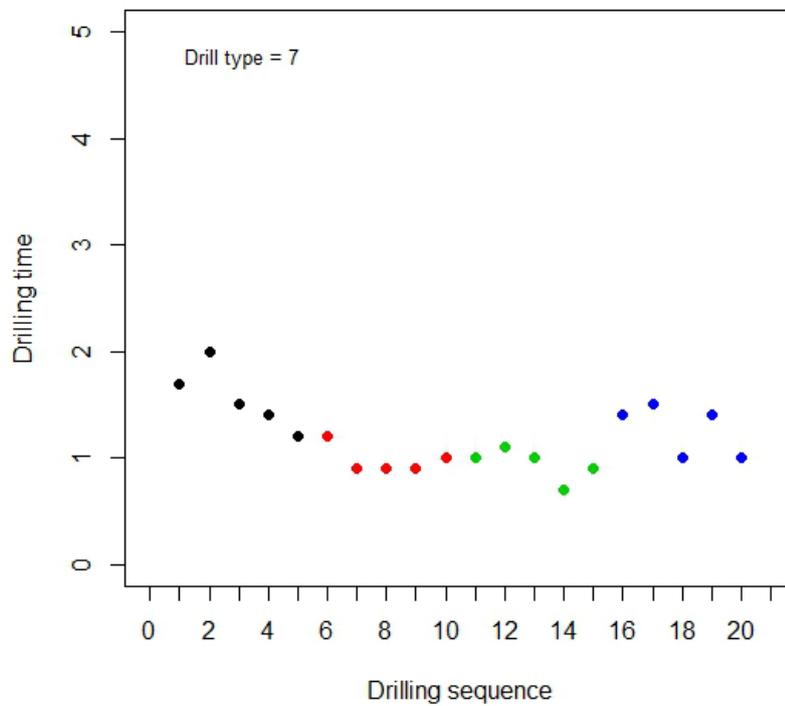


**Figure 16: Group 2(DLC) drill type 5.**

**5.2.3. Group three:** Two stainless steel drills (MEGAGEN Jain-Myun Gyeongsan, Gyeongbuk, Korea) - the first drill measurements averaged 2.2 seconds and reduced steadily to the 15<sup>th</sup> attempt, where an average of 0.75 seconds was recorded. The trend then increased gradually to 1.3 seconds. (Refer to Figure 17 and 18).

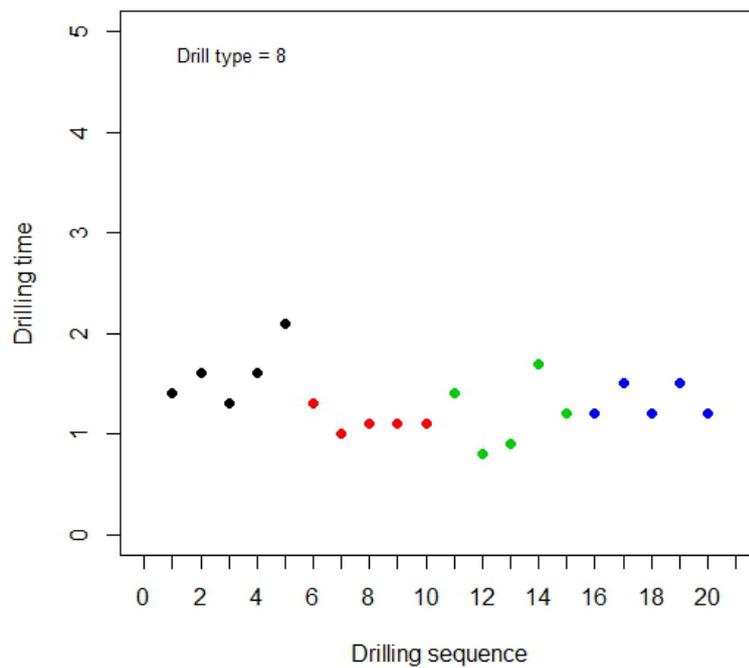


**Figure 17: Group 3 (SS) drill type 6 .**



**Figure 18: Group 3 (SS) drill type 7.**

**5.2.4. Group four:** Three stainless steel drills (Straumann Pasel, Switzerland) - the first drill measurements averaged 1.65 seconds followed by a steady but gradual decrease in time to an average of 1.1 seconds in the 12<sup>th</sup> drilling. The trend then gradually increased to 1.2 seconds in an erratic fashion. (Refer to Figure 19, 20, and 21)



**Figure 19: Group 4(SS) drill type 8.**

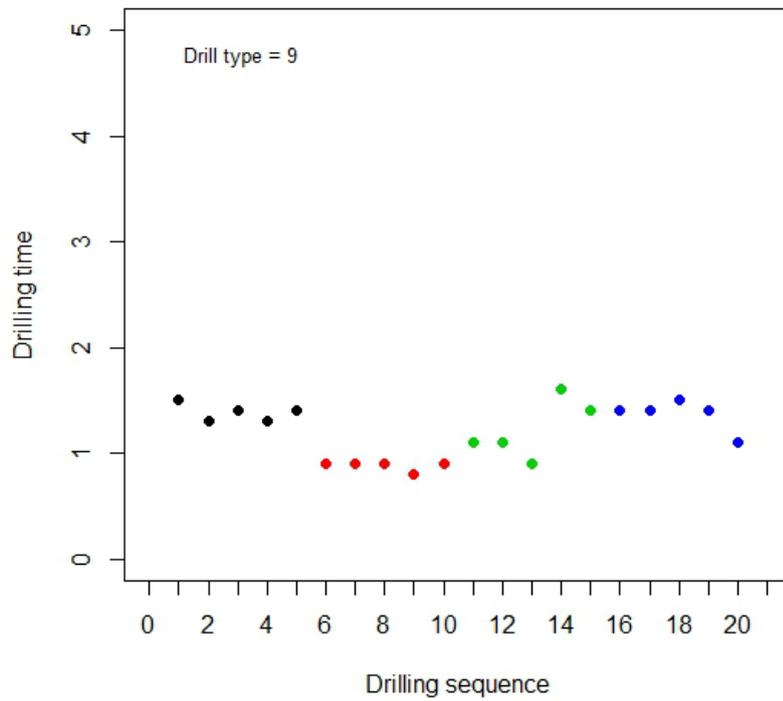


Figure 20: Group 4 (SS) drill type 9  
 UNIVERSITY of the

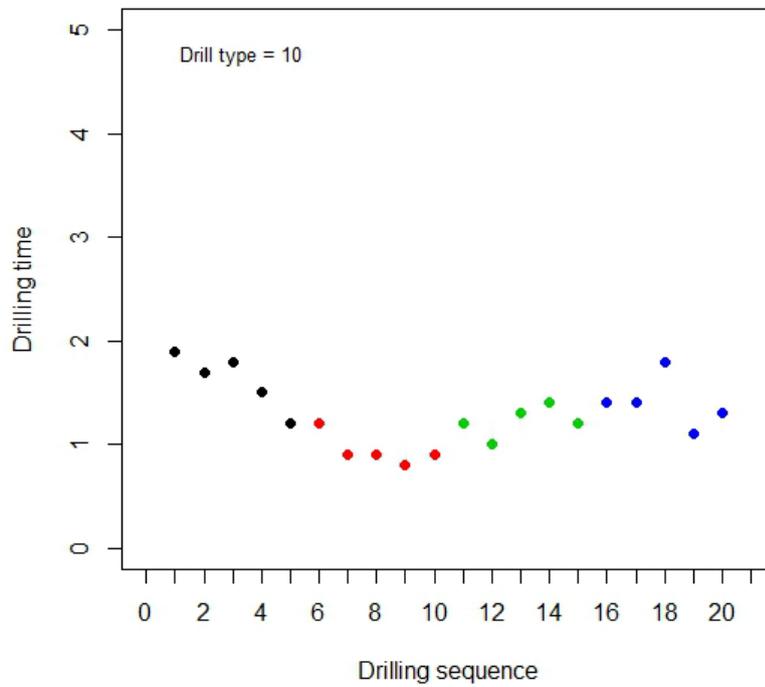
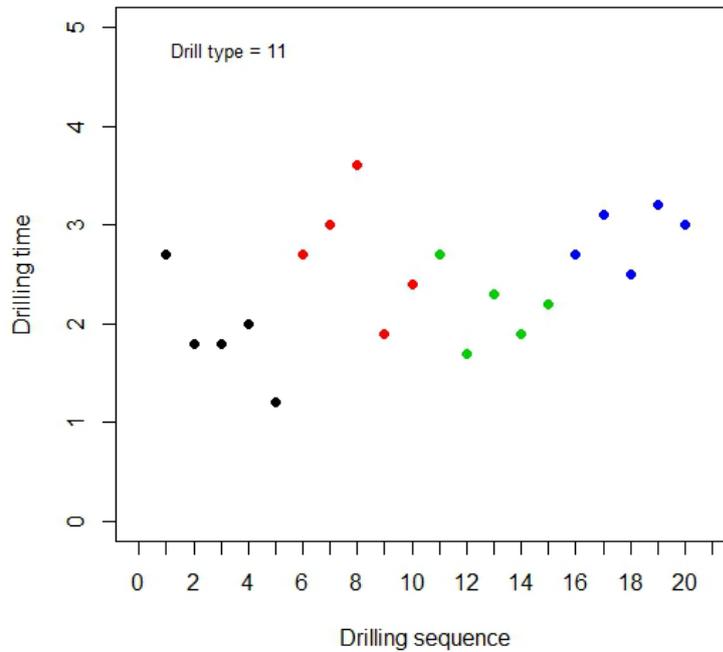
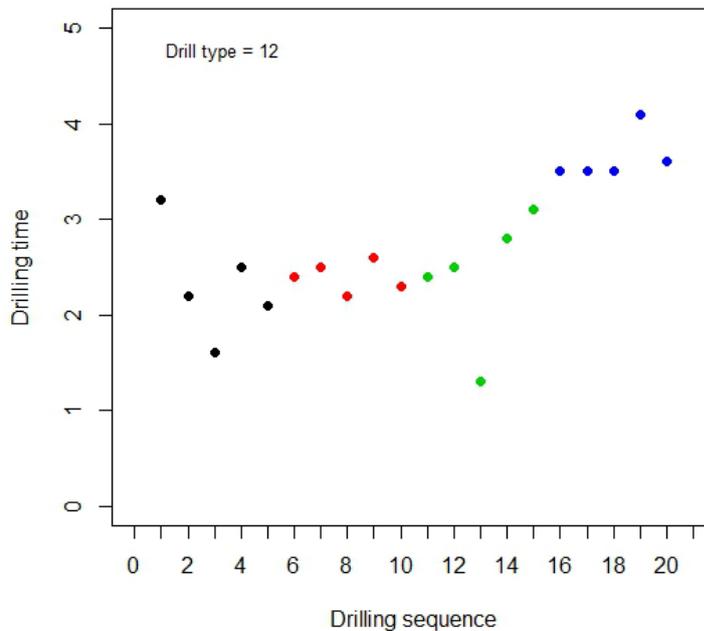


Figure 21: Group 4 (SS) drill type 10.

**5.2.5. Group five:** Three stainless steel drills (Champions Implants. GmbH, Platz, Germany) - the first drill measurements averaged 2.4 seconds and gradually decreased to 1.7 seconds by the 7th drilling. Thereafter a gradual and steady increase was observed of 3.3 seconds in the final drillings. (Refer to Figures 22, 23, and 24).



**Figure 22: Group 5 (SS) drill type 11.**



**Figure 23: Group 5 (SS) drill type 12.**

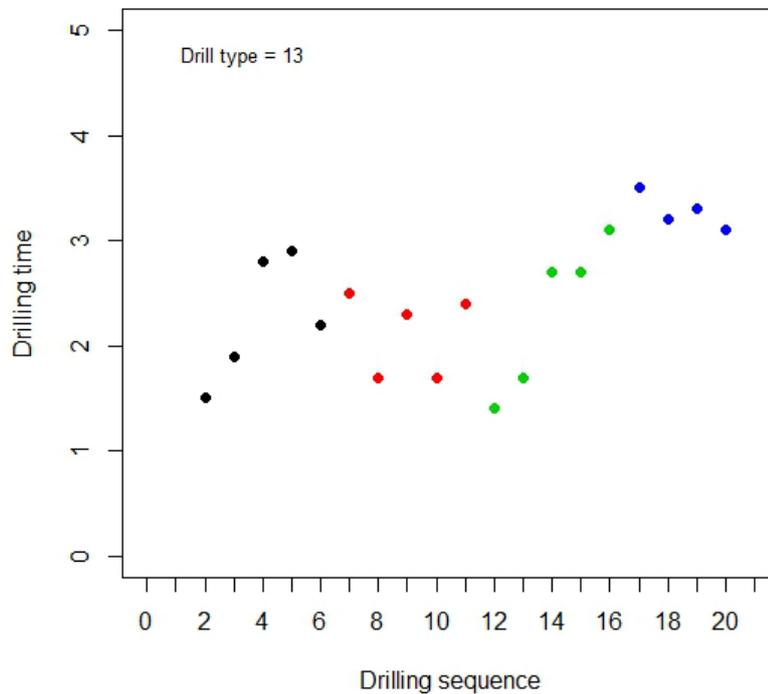


Figure 24: Group 5 (SS) drill type 13.



### 5.3. Summary of the results:

The Figure below shows a summary of the means as well as the various drill speed patterns. The first four groups show a common pattern with an initial increase in speed observed, followed by a gradual and steady reduction in time. Of note was the results of the fifth group (blue line) which demonstrated higher numbers throughout the drilling sequence and the erratic plotting observed appeared much higher than the previous four groups (Figure 25). Table 2 below shows the mean values for the 13 Drill.

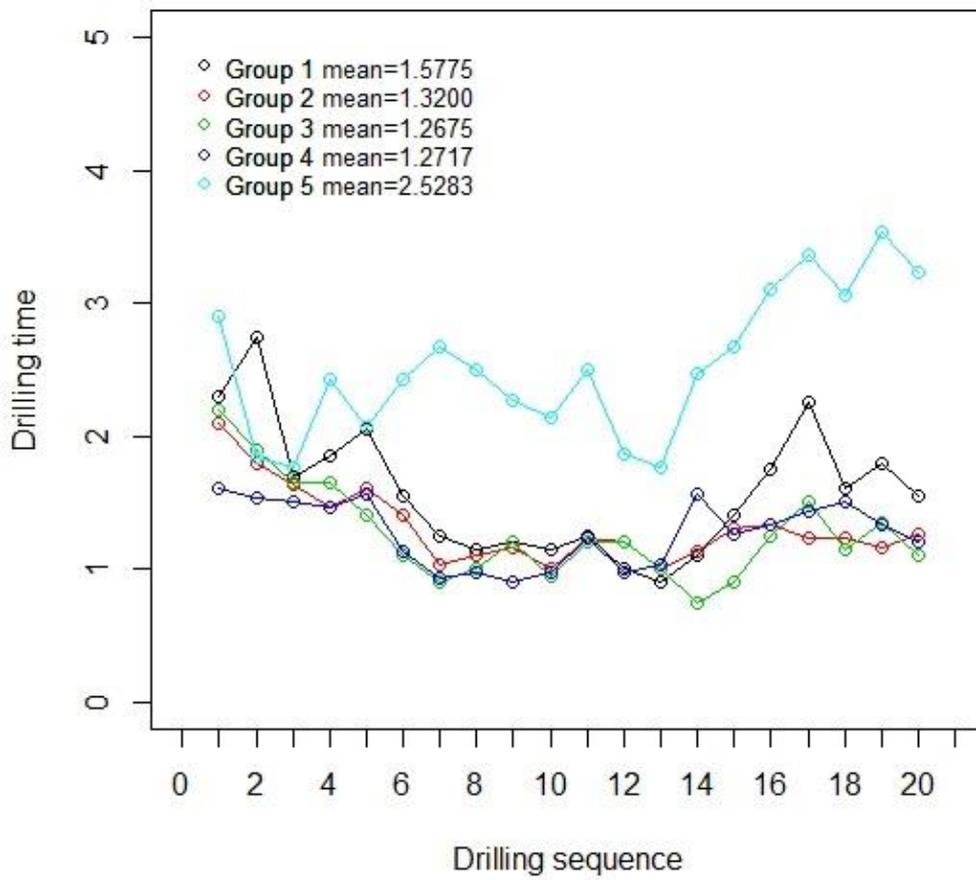


Figure 25: Means of five groups with drilling times/drilling sequences.

**Table 2: Means by Drill Type and Session.**

Drill type	Session				P-value	Mean
	1	2	3	4		
<b>1</b>	2.14	1.28	1.02	1.66	0.004	1.525
<b>2</b>	2.12	1.24	1.24	1.92	0.001	1.630
<b>3</b>	1.86	1.26	1.06	1.46	0.002	1.410
<b>4</b>	1.74	1.18	1.22	1.22	0.001	1.340
<b>5</b>	1.56	0.98	1.24	1.06	0.002	1.210
<b>6</b>	1.96	1.08	1.08	1.28	0.001	1.350
<b>7</b>	1.56	0.98	0.94	1.26	0.001	1.185
<b>8</b>	1.60	1.12	1.20	1.32	0.048	1.310
<b>9</b>	1.38	0.88	1.22	1.36	0.001	1.210
<b>10</b>	1.62	0.94	1.22	1.40	0.001	1.295
<b>11</b>	1.90	2.72	2.16	2.90	0.015	2.420
<b>12</b>	2.32	2.40	2.42	3.64	0.001	2.695
<b>13</b>	2.38	2.08	2.18	3.24	0.025	2.470
<b>Mean</b>	1.857	1.395	1.400	1.825		

**Table 3: Means of five groups with S.E.**

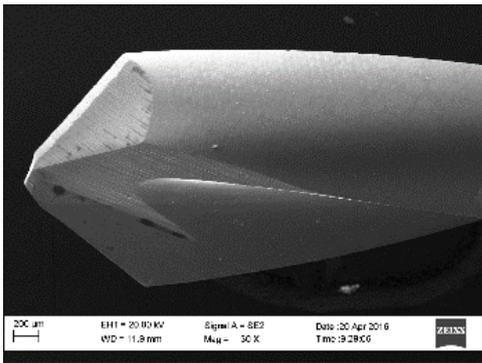
Group	1	2	3	4	5
<b>Mean</b>	1.5775	1.3200	1.2675	1.2717	2.5283
<b>S.E</b>	0.0506	0.04130	0.0506	0.04130	0.04130

#### **5.4. Scanning Electron Microscopy (SEM) analysis:**

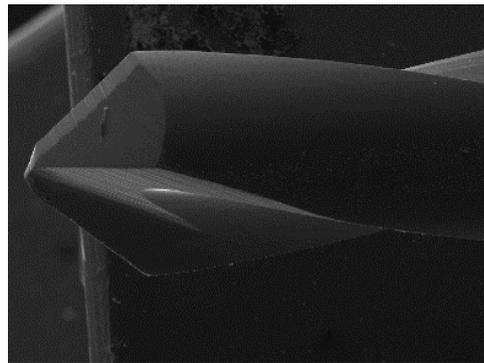
All implant drills from the various groups (G1, G2, G3, and G5) showed signs of wear after 20 uses. Evaluation of the drill surfaces was conducted after intervals of five, 10, 15 uses and 20 uses. The first three surface examinations were done at 30X magnification. The last examination after 20 uses was conducted at 150 X magnification. The later revealed damage to the cutting surface and blunting of the tips, with coating delamination detected in the diamond-like carbon (DLC) drills in group G2 (see Figure 29, Figure 34 and Figure 39 respectively). Drills from groups G1, G3, and G5 showed irregular surfaces and a higher tip wear of both edges (Figures: 19, 24, 44, 49, 69, 74, and 79). In contrast, stainless steel drills from group G4 maintained regular surfaces of the cutting edges, with no difference before and after drilling procedures noted (Figures: 54, 59 and 64).



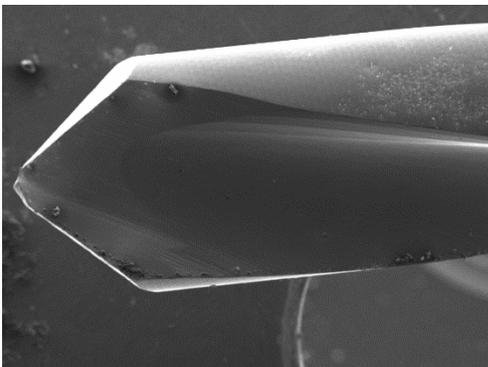
## Sequence of images of drill surfaces



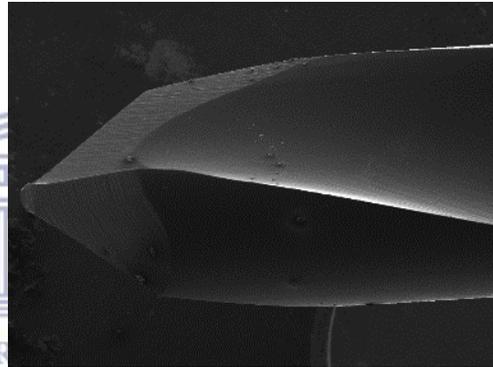
**Figure 26: Drill type 1(G1)  
Before drilling.**



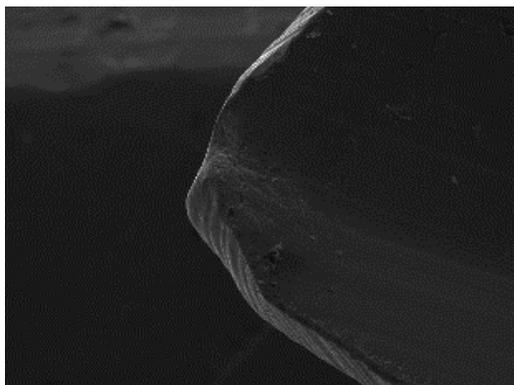
**Figure 27: Drill type1 (G1)  
After drilling 5 times.**



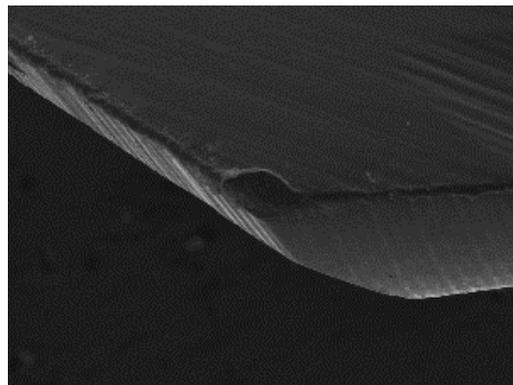
**Figure28: Drill type1 (G1)  
After drilling 10 times.**



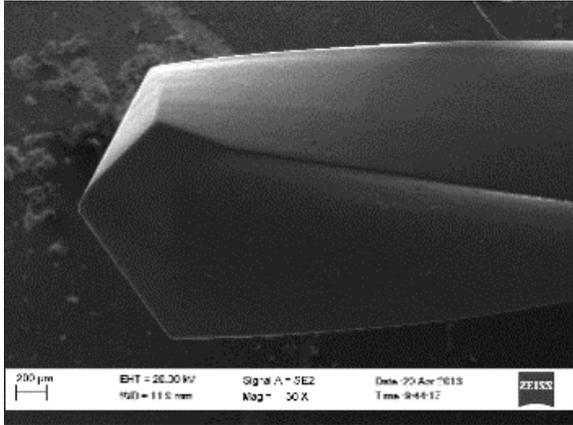
**Figur29: Drill type1 (G1)  
After drilling 15 times.**



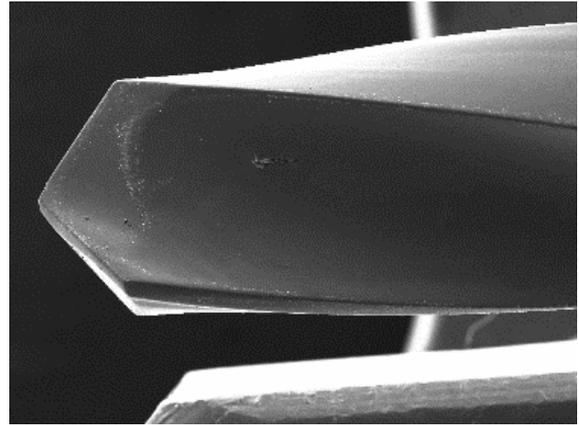
**Figure 30(a): Drill type 1 (G1)  
(Drill tip) after drilling 20 times.**



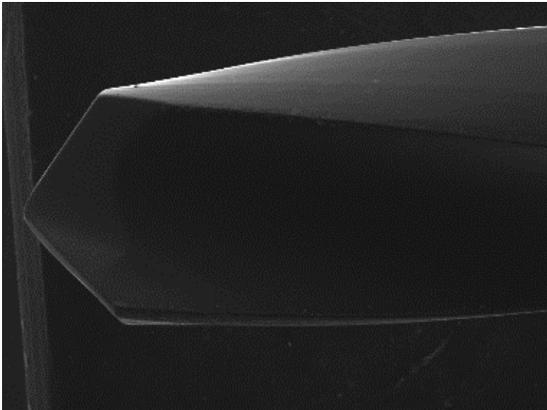
**Figure 30(b): Drill type 1(G1)  
(Edge side) after drilling 20 times.**



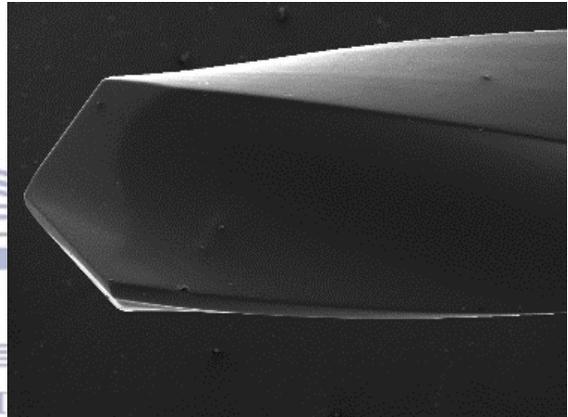
**Figure 31: Drill type 2 (G1)  
Before drilling.**



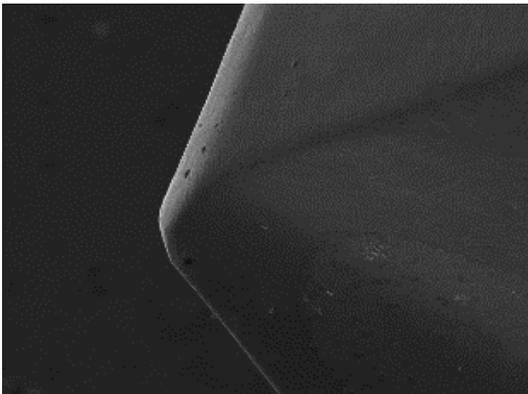
**Figure 32: Drill type 2 (G1)  
After drilling 5 times.**



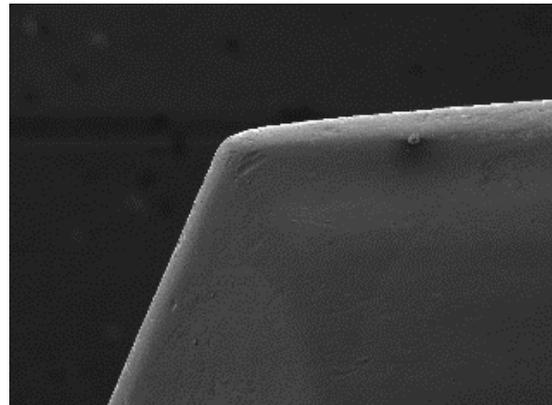
**Figure 33: Drill type 2 (G1)  
After 10 drilling times.**



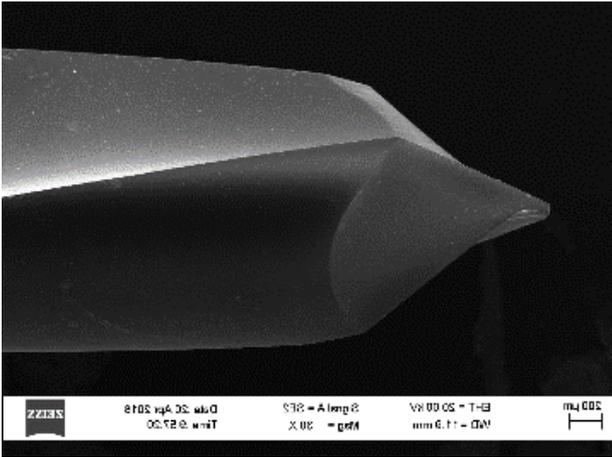
**Figure 34: Drill type 2 (G1)  
After drilling 15 times.**



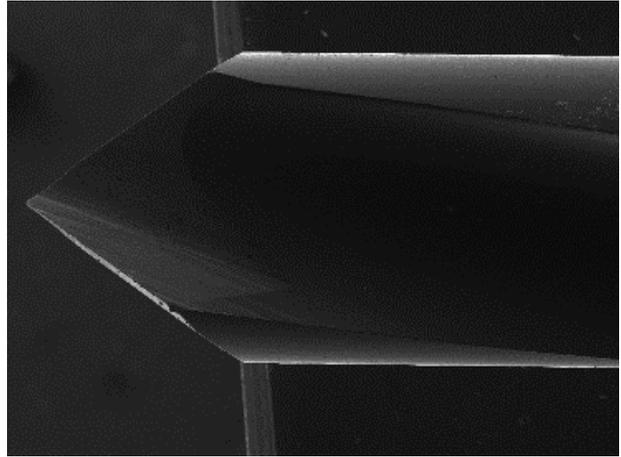
**Figure 35(a): Drill type 2 (G1)  
(Drill tip) after drilling 20 times.**



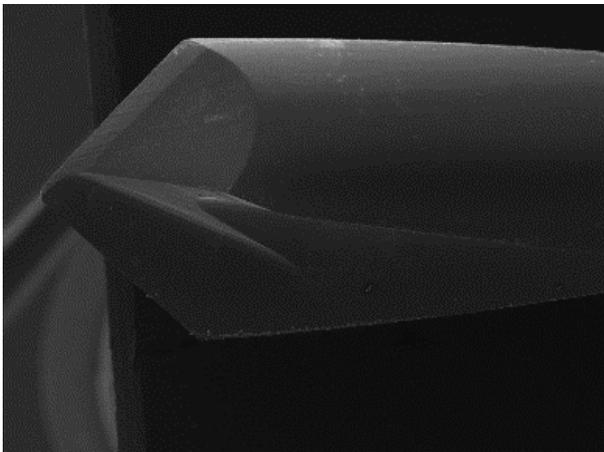
**Figure 35(a): Drill type 2 (G1)  
(Edge side) after drilling 20 times.**



**Figure 36: Drill type 3(G2)**

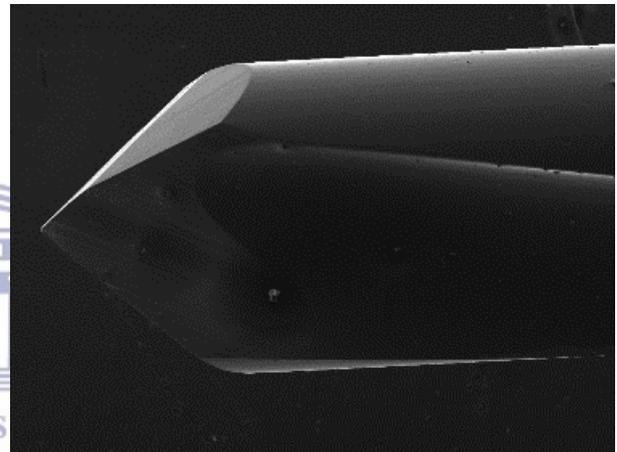


**Figure 37: Drill type 3(G2)**



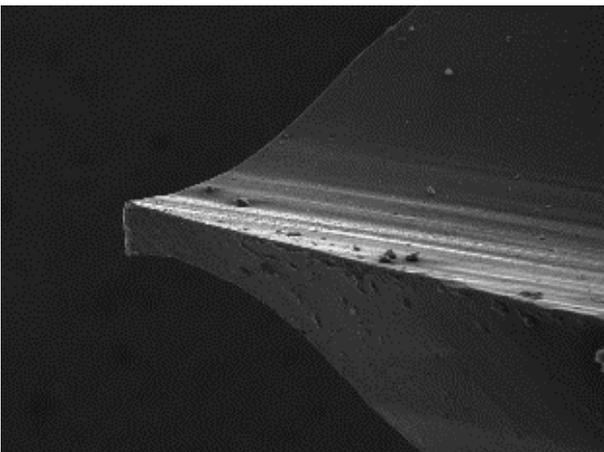
**Before drilling.**

**Figure 38: Drill type 3(G2)**



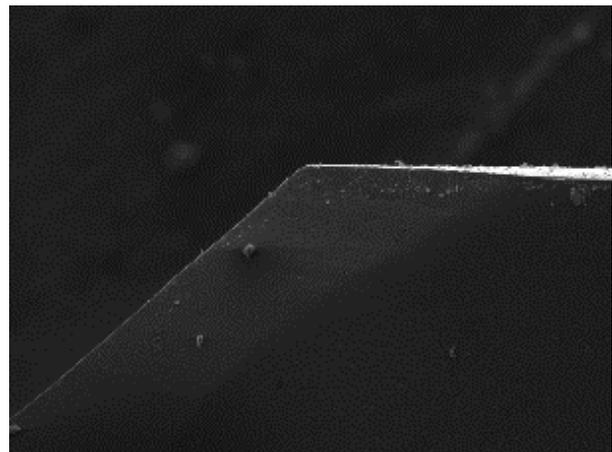
**After drilling 5 times.**

**Figure 39: Drill type 3(G2)**



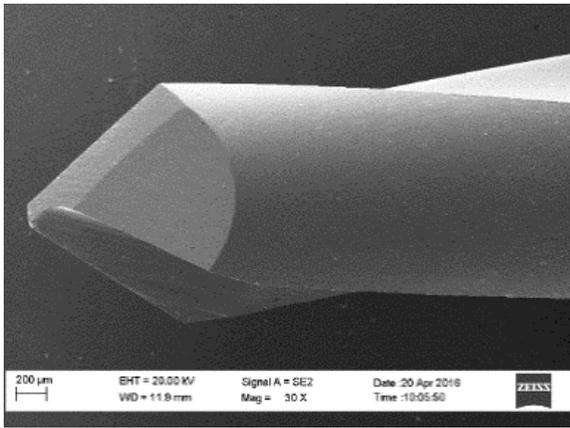
**After drilling 10 times.**

**Figure 40(a): Drill type 3(G2)  
(Drill tip) after drilling 20 times.**

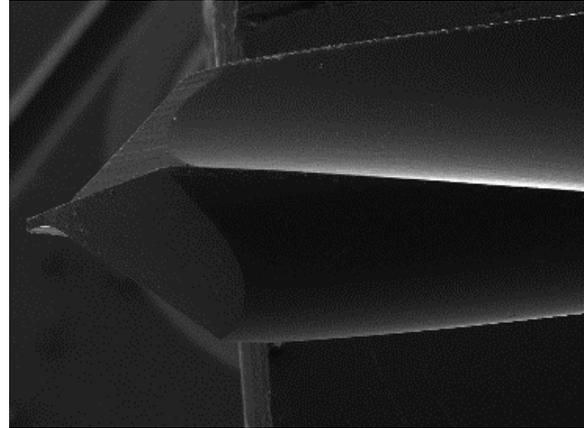


**After drilling 15 times.**

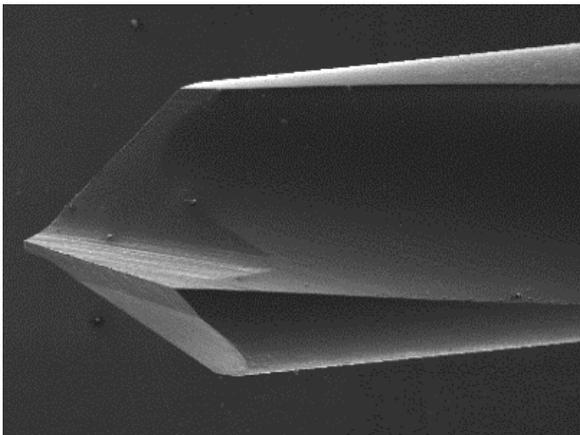
**Figure 40(a): Drill type 3(G2)  
(Edge side) after drilling 20 times.**



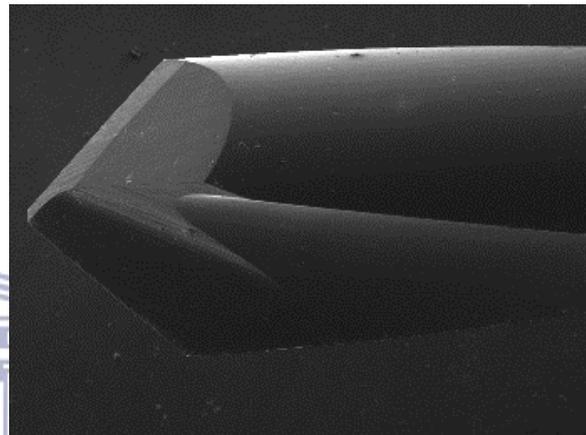
**Figure 41: Drill type 4(G2)  
Before drilling.**



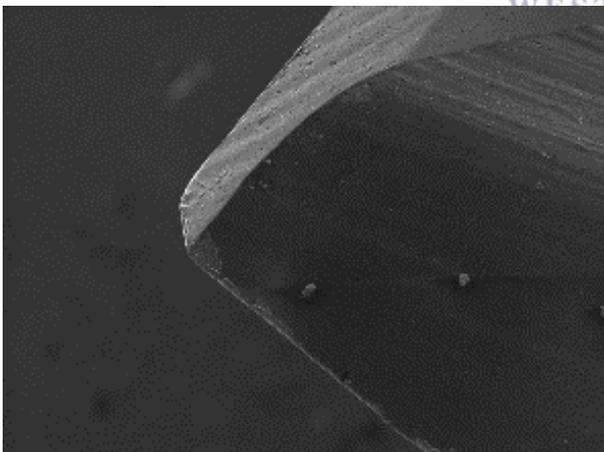
**Figure 42: Drill type 4(G2)  
After drilling 5 times.**



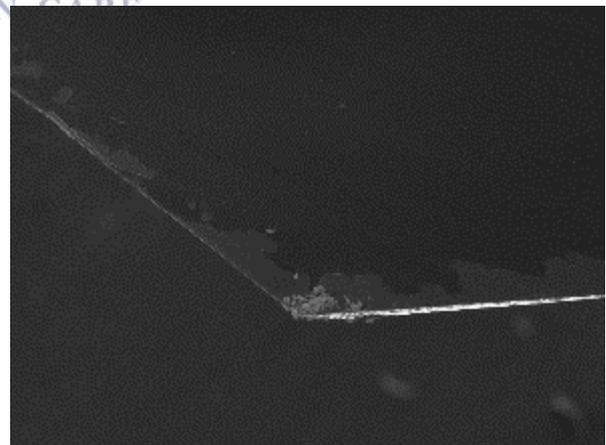
**Figure 43: Drill type 4(G2)  
After drilling 10 times.**



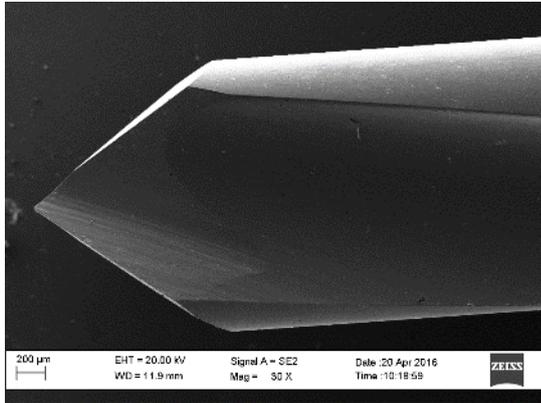
**Figure 44: Drill type 4(G2)  
After drilling 15 times.**



**Figure 45(b): drill type 4(G2)  
(Drill tip) after drilling 20 times.**

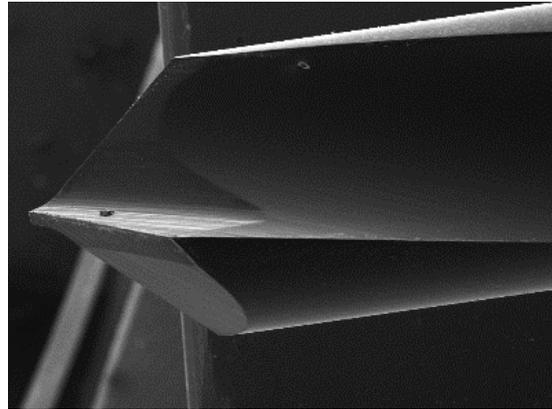


**Figure 45(a): drill type 4(G2)  
(Edge side) after drilling 20 times.**



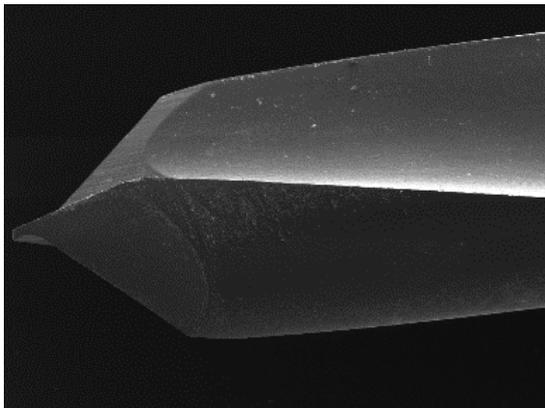
**Figure 46: Drill type 5(G2)**

**Before drilling.**



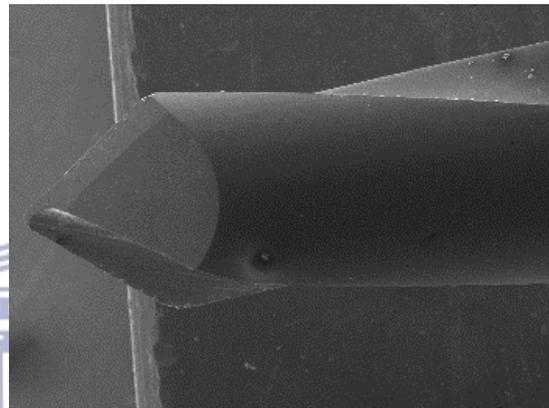
**Figure 47: Drill type 5(G2)**

**After drilling 5 times.**



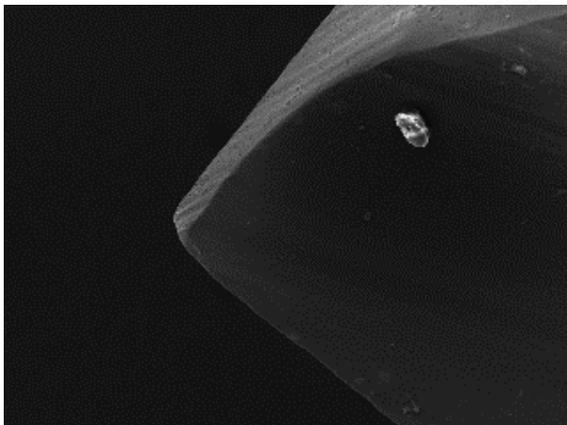
**Figure 48: Drill type 5(G2)**

**After drilling 10 times.**

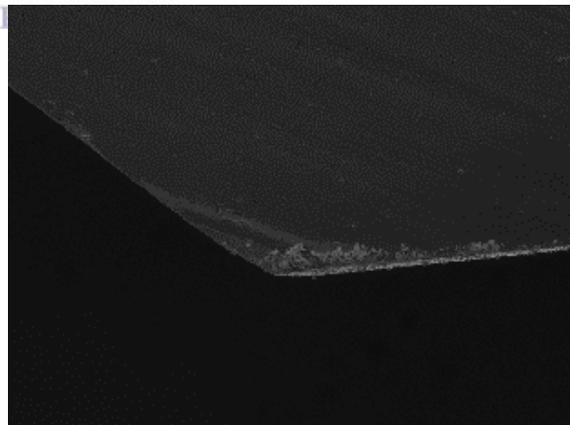


**Figure 49: Drill type 5(G2)**

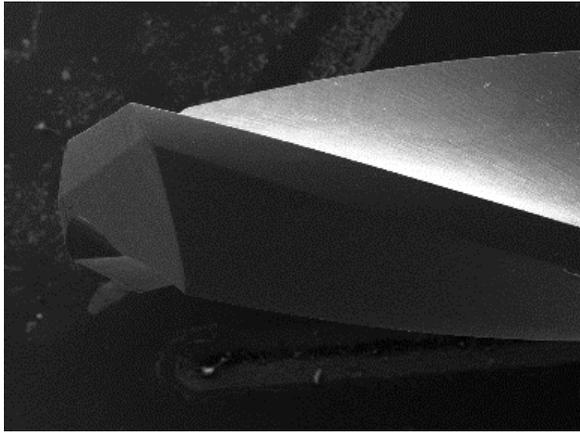
**After drilling 15 times.**



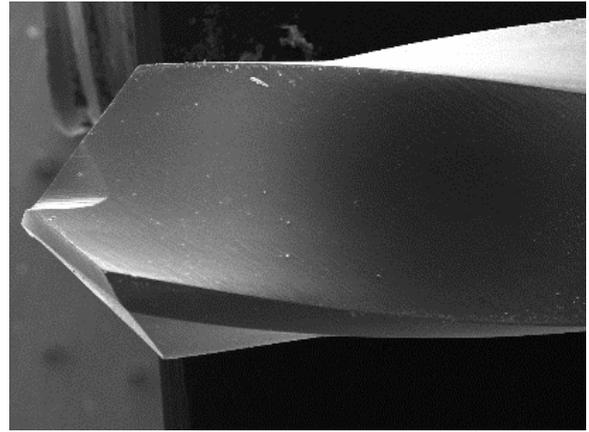
**Figure 50(a): Drill type 5(G2)  
(Drill type) after drilling 20 times.**



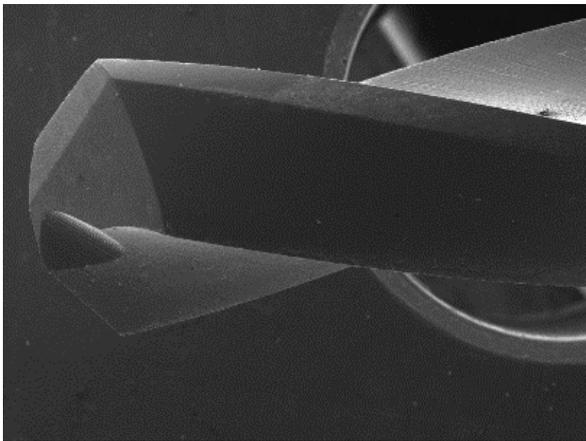
**Figure 50(b): Drill type 5(G2)  
(Edge side) after drilling 20 times.**



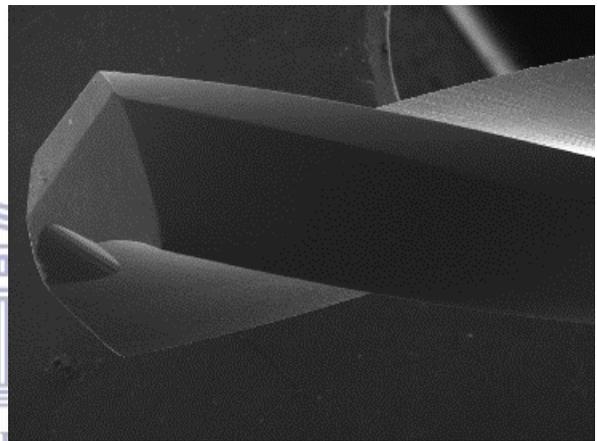
**Figure 51: Drill type 6(G3)  
Before drilling.**



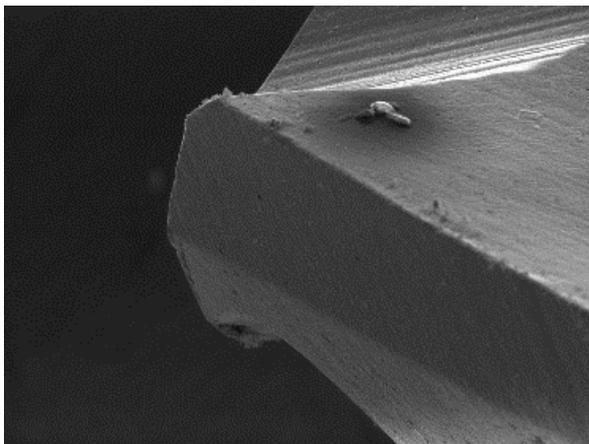
**Figure 52: Drill type 6(G3)  
After drilling 5 times.**



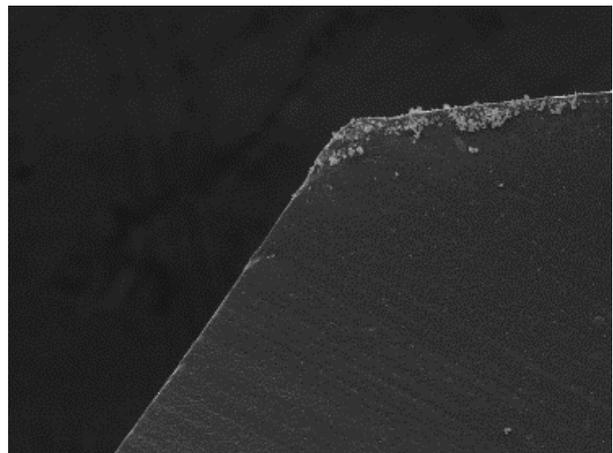
**Figure 53: Drill type 6(G3)  
After drilling 10 times.**



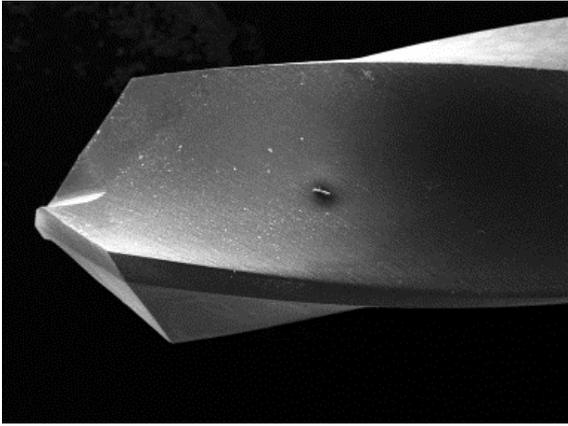
**Figure 54: Drill type 6(G3)  
After drilling 15 times.**



**Figure 55 (a): Drill type 6(G3)  
(Drill tip) after drilling 20 times.**

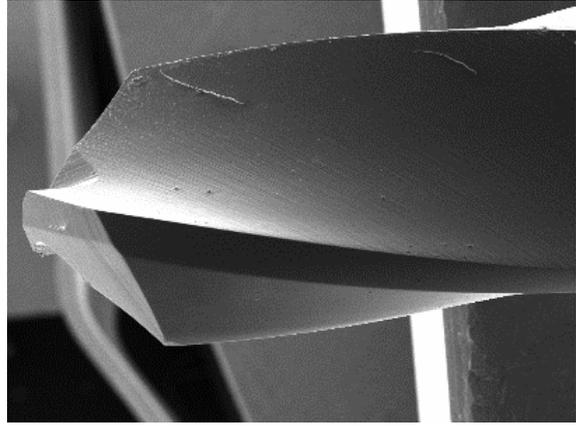


**Figure 55(b): Drill type 6(G3)  
(Edge side) after drilling 20 times.**



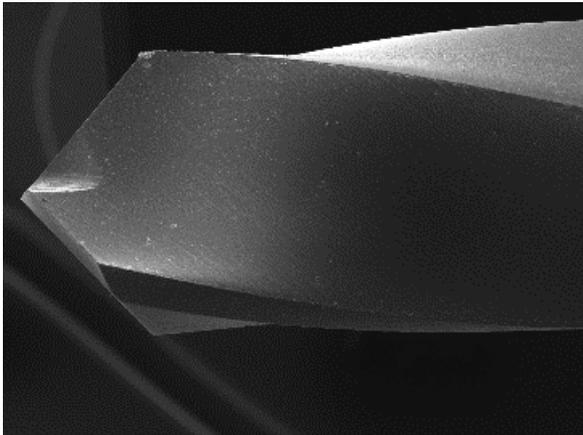
**Figure 56: Drill type 7(G3)**

**Before drilling.**

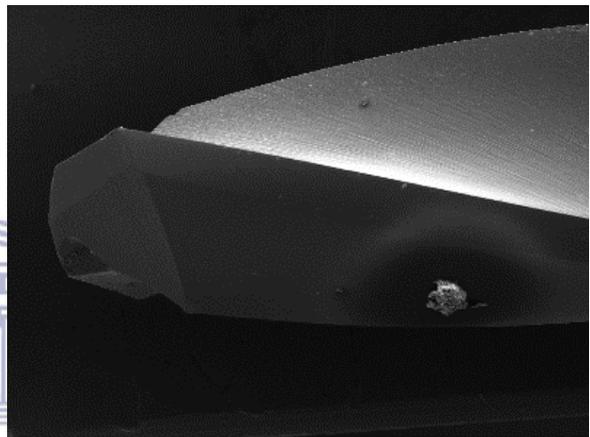


**Figure 57: Drill type 7(G3)**

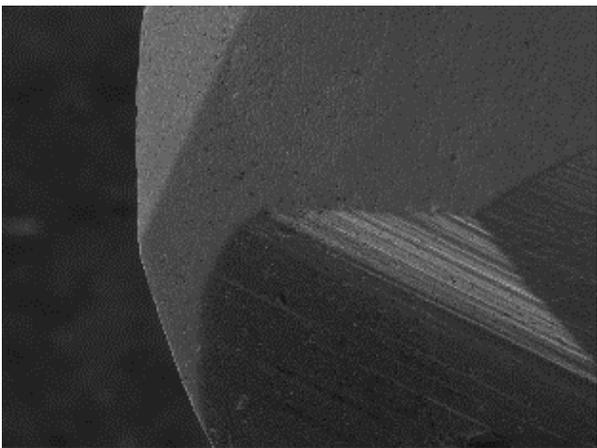
**After drilling 5 times.**



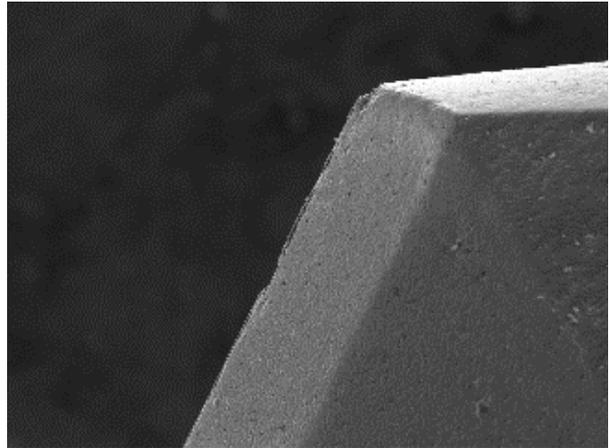
**Figure 58: Drill type 7(G3)**  
**After drilling 10 times.**



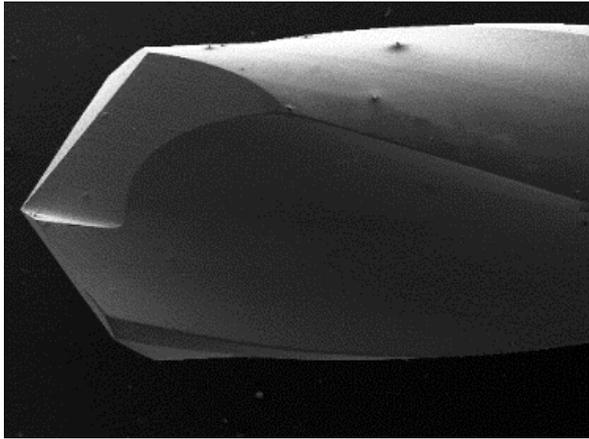
**Figure 59: Drill type 7(G3)**  
**After drilling 15 times.**



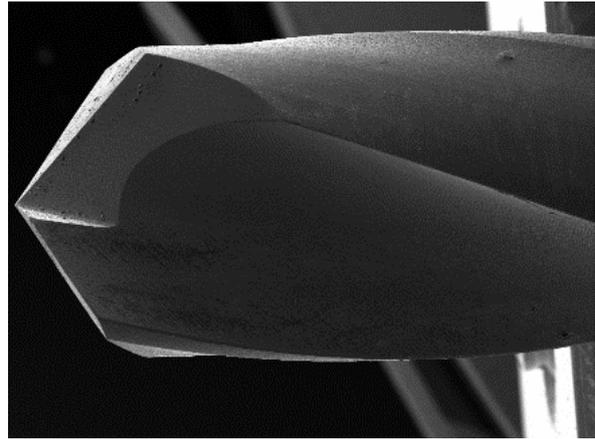
**Figure 60(a): Drill type 7(G3)**  
**(Drill tip) after drilling 20 times.**



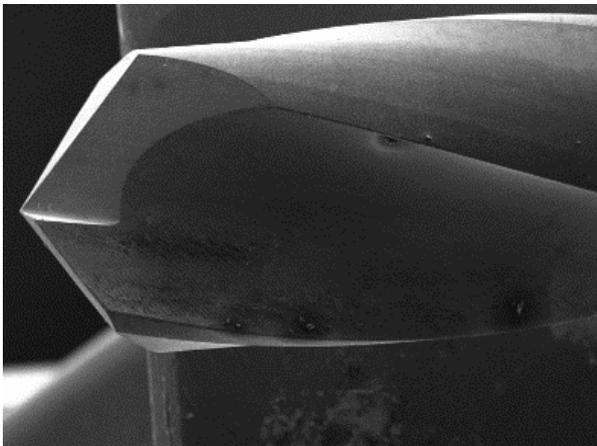
**Figure 60(a): Drill type 7(G3)**  
**(Edge side) after drilling 20 times.**



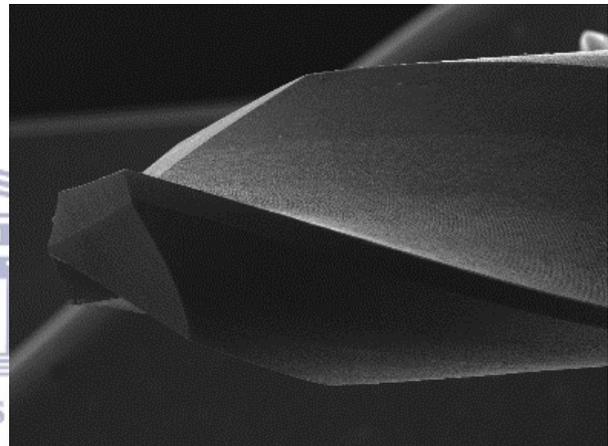
**Figure 61: Drill type 8(G4)  
Before drilling.**



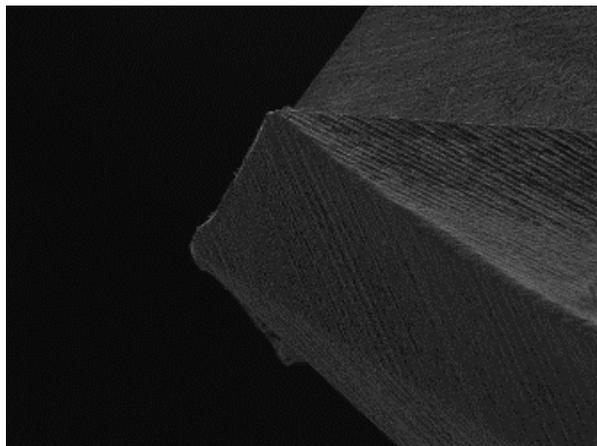
**Figure 62: Drill type 8(G4)  
After drilling 5 times.**



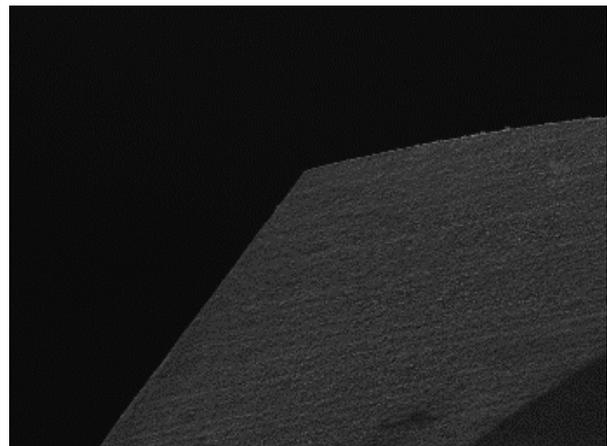
**Figure 63: Drill type 8(G4)  
After drilling 10 times.**



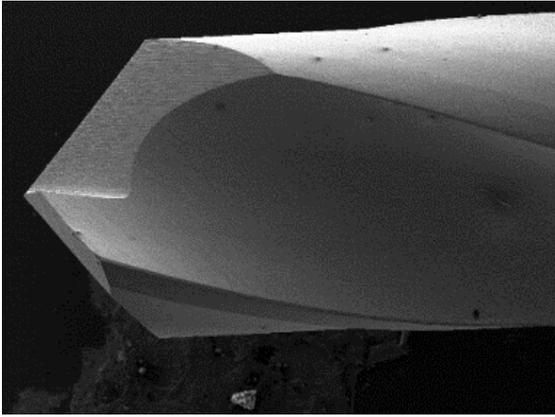
**Figure 64: Drill type 8(G4)  
After drilling 15 times.**



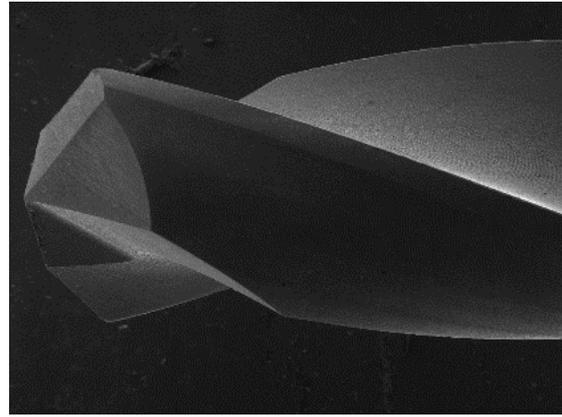
**Figure 65(a): Drill type 8(G4)  
(Drill tip) after drilling 20 times.**



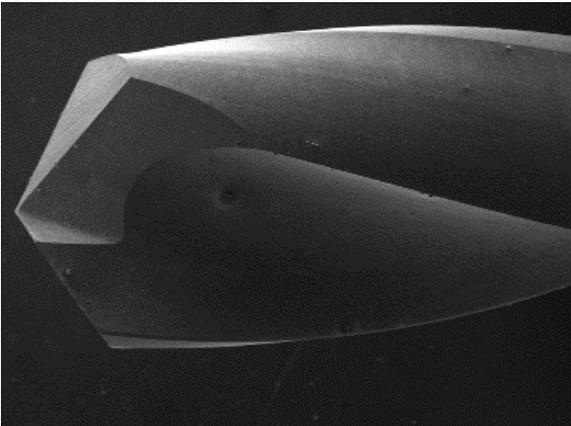
**Figure 65(b): Drill type 8(G4)  
(Edge side) after drilling 20 times.**



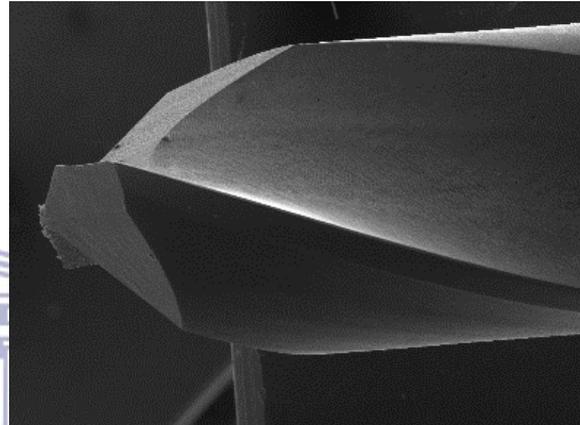
**Figure 66: Drill type 9(G4)  
Before drilling.**



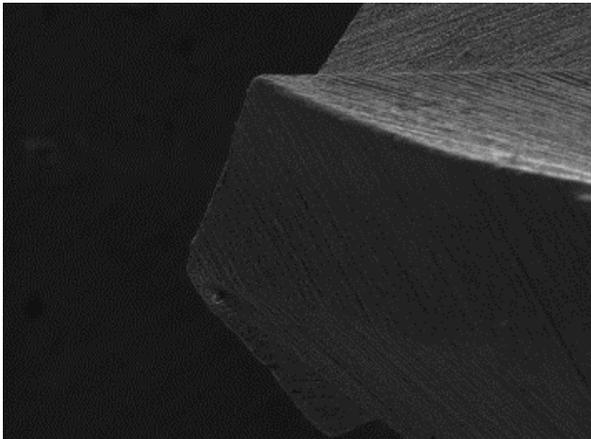
**Figure 67: Drill type 9(G4)  
After drilling 5 times.**



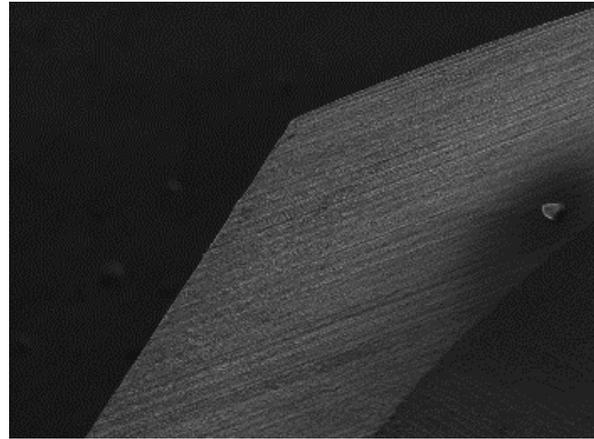
**Figure 68: Drill type 9(G4)  
After drilling 10 times.**



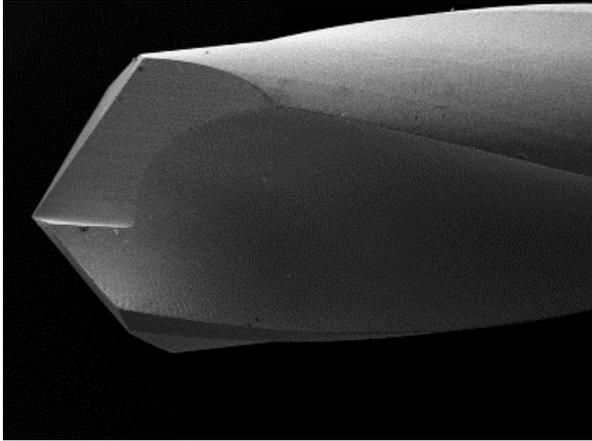
**Figure 69: Drill type 9(G4)  
After drilling 15 times.**



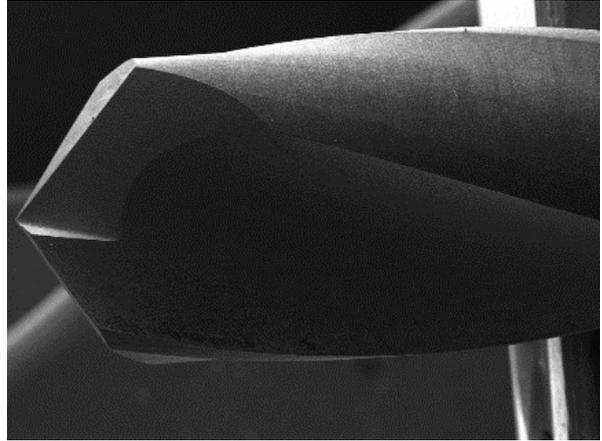
**Figure 70(a): Drill type 9(G4)  
(Drill tip) after drilling 20 times.**



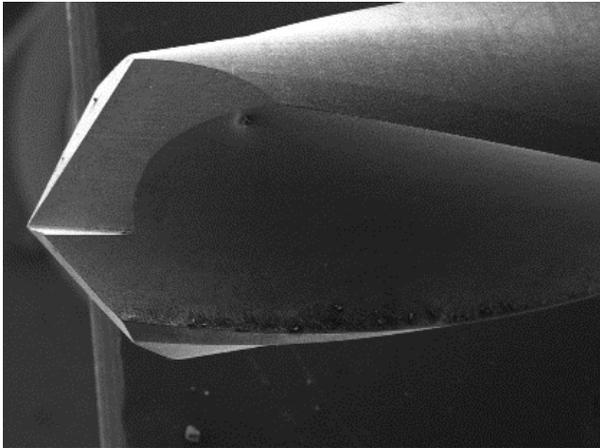
**Figure 70(b): Drill type 9(G4)  
(Edge side) after drilling 20 times.**



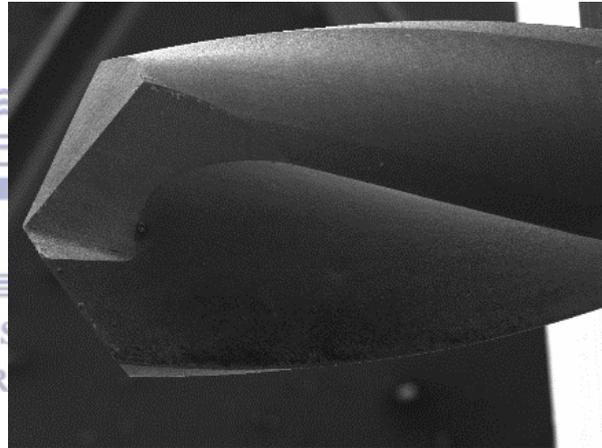
**Figure 71: Drill type 10(G4)**  
**Before drilling.**



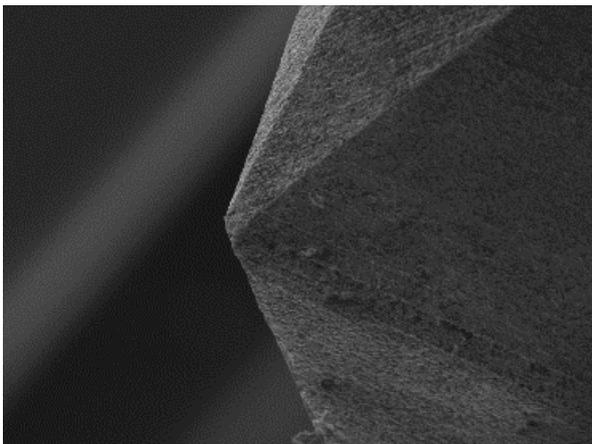
**Figure 72: Drill type 10(G4)**  
**After drilling 5 times.**



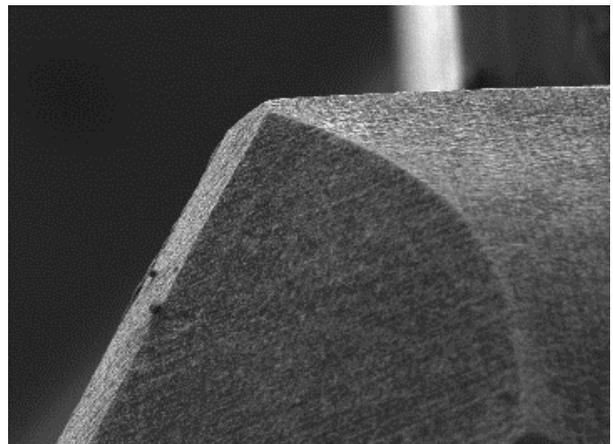
**Figure 73: Drill type 10(G4)**  
**After drilling 10 times.**



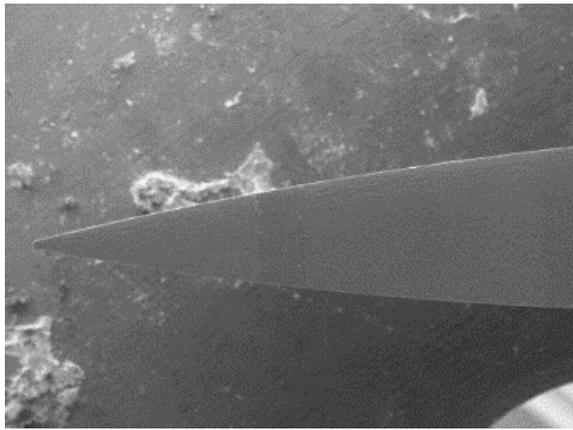
**Figure 74: Drill type 10(G4)**  
**After drilling 15 times.**



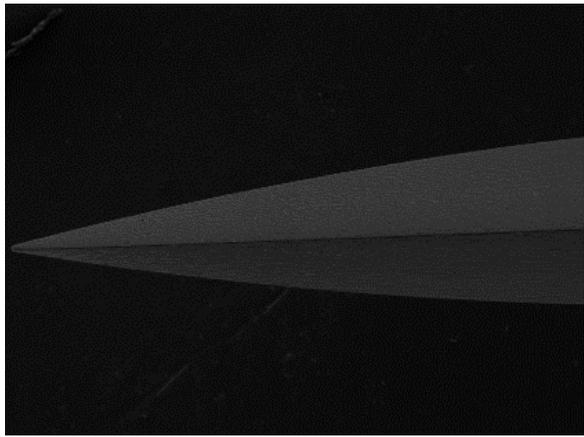
**Figure 75(a): Drill type 10(G4)**  
**(Drill tip) after drilling 20 times.**



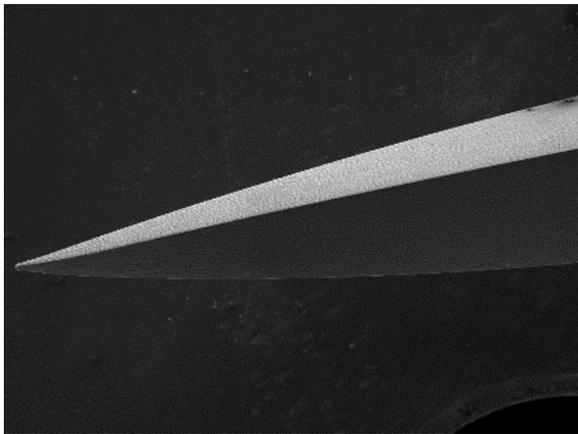
**Figure 75(b): Drill type 10(G4)**  
**(Edge side) after drilling 20 times.**



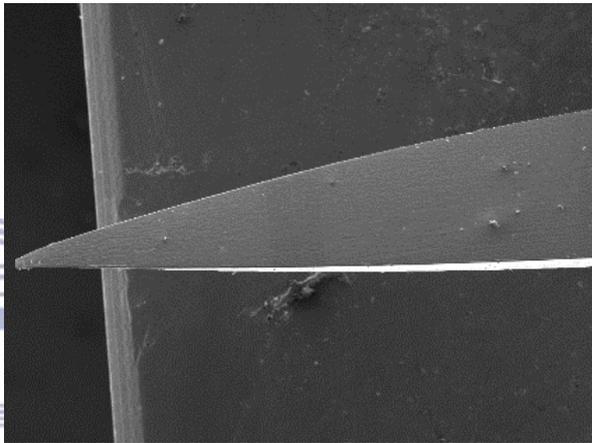
**Figure 76: Drill type 11(G5)  
Before drilling.**



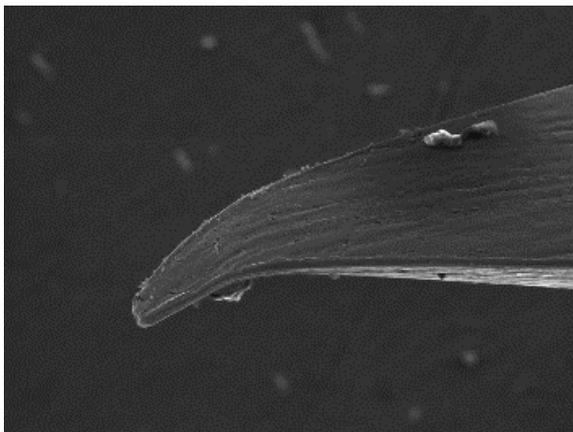
**Figure 77: Drill type 11(G5)  
After drilling 5 times.**



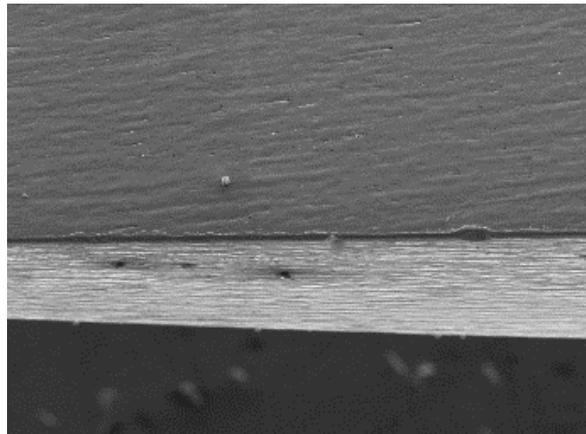
**Figure 78: Drill type 11(G5)  
After drilling 10 times.**



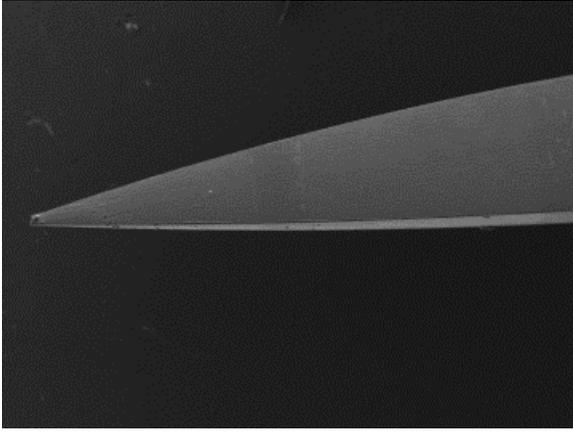
**Figure 79: Drill type 11(G5)  
After drilling 15 times.**



**Figure 80(a): Drill type 11(G5)  
(Drill tip) after drilling 20 times.**

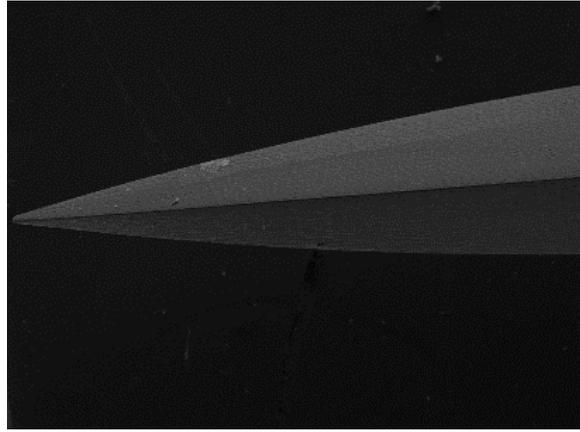


**Figure 80(b): Drill type 64(G5)  
(Edge side) after drilling 20 times.**



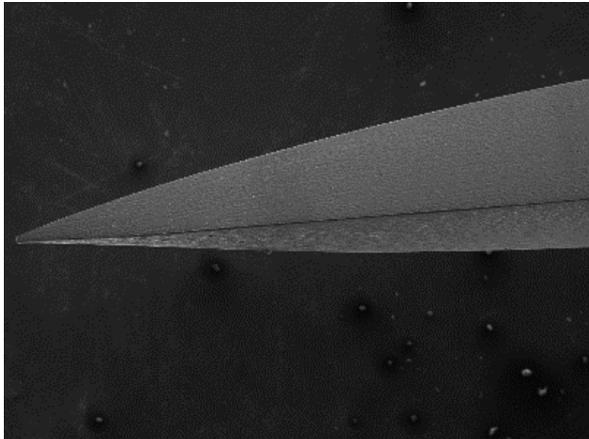
**Figure 81: Drill type 12(G5)**

**Before drilling.**



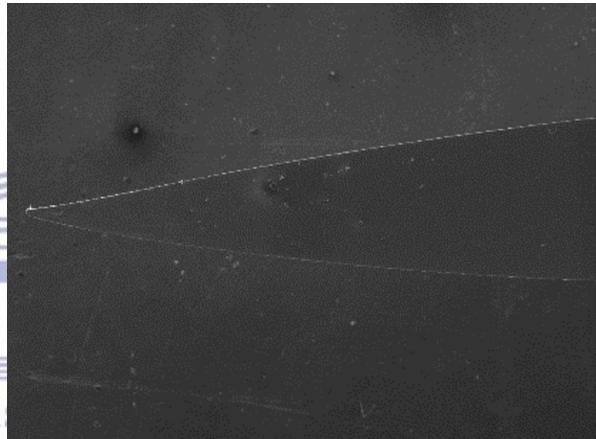
**Figure 82: Drill type 12(G5)**

**After drilling 5 times.**



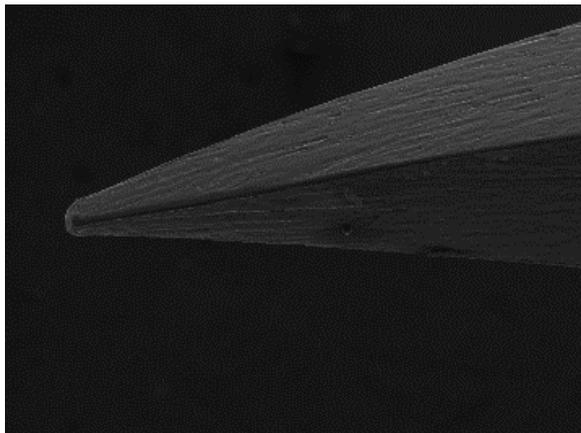
**Figure 83: Drill type 12(G5)**

**After drilling 10 times.**

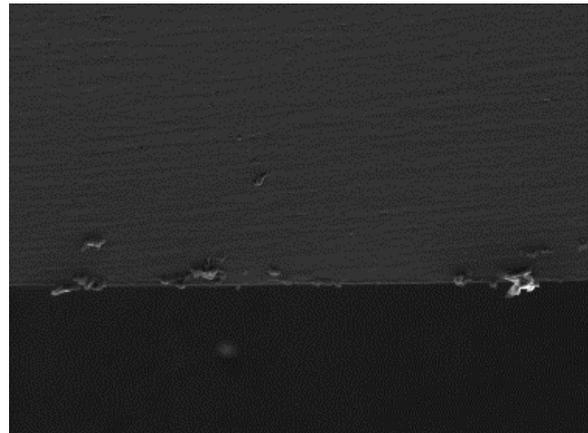


**Figure 84: Drill type 12(G5)**

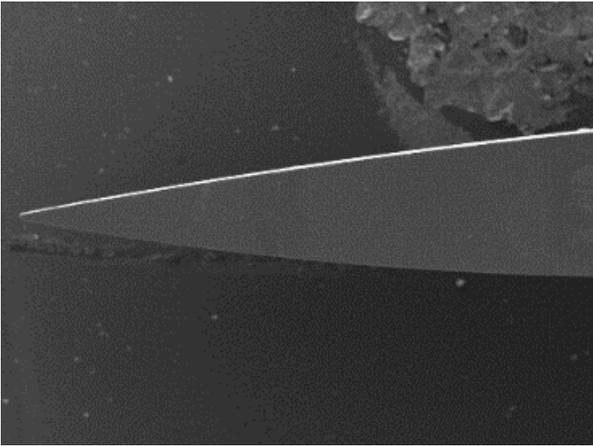
**After drilling 15 times.**



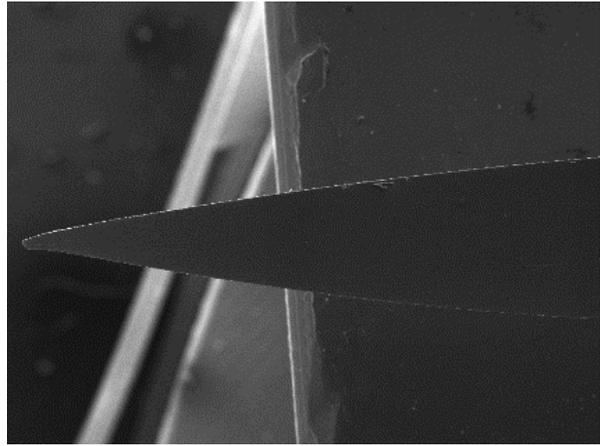
**Figure 85(a): Drill type 12(G5)**  
**(cutting tip) after drilling 20 times.**



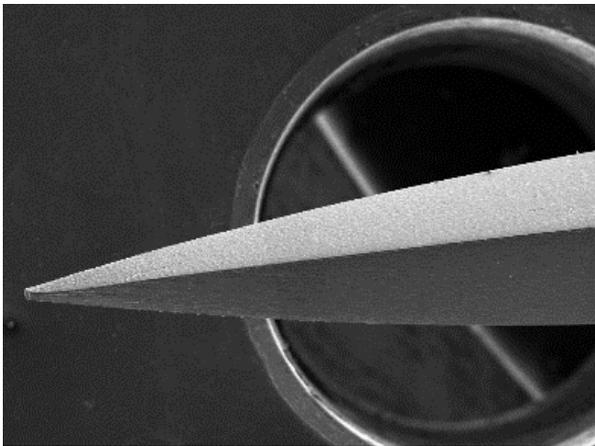
**Figure 85(b): Drill type 12(G5)**  
**(Edge side) after drilling 20 times.**



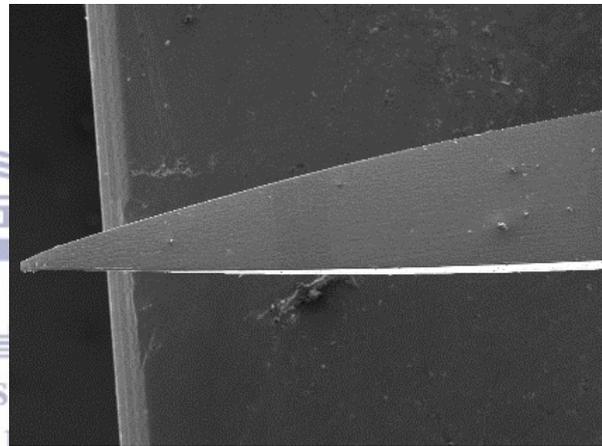
**Figure 86: Drill type 13(G5)**  
**Before drilling.**



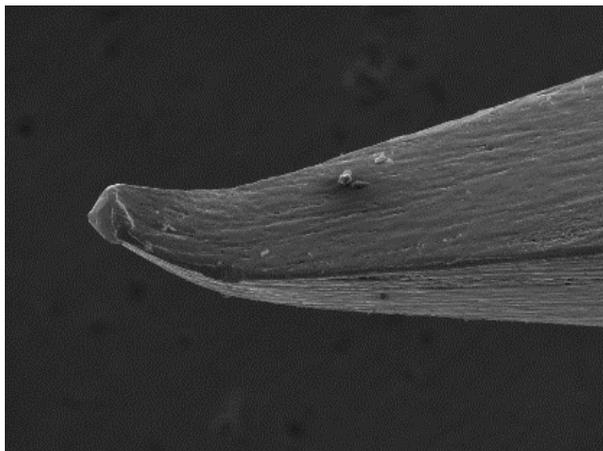
**Figure 87: Drill type 13(G5)**  
**After drilling 5 times.**



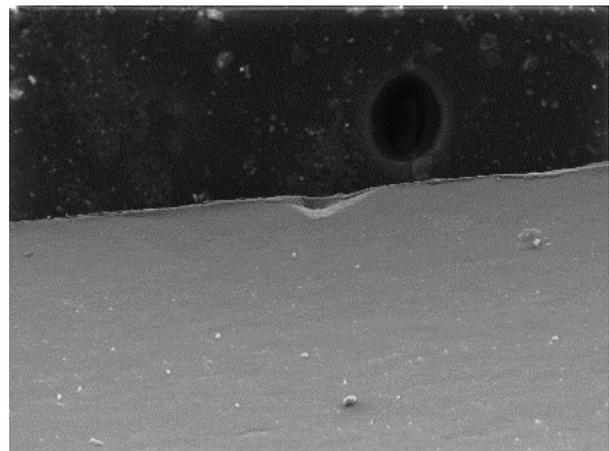
**Figure 88: Drill type 13(G5)**  
**After drilling 10 times.**



**Figure 89: Drill type 13(G5)**  
**After drilling 15 times.**



**Figure 90(a): Drill type 13(G5)**  
**(Cutting tip) After drilling 20 times.**



**Figure 90(b): Drill type 13(G5)**  
**(Edge side) after drilling 20 times.**

### **5.5. Summary of the results of SEM analysis:**

In SEM image, there was no different between DLC coating and SS after being used 20 times except Champions Implant drills G5 recommended that the drill should not be used more than five times at low speed 250 rpm. The discussion of these results will be in chapter 6.



# Chapter 6

## Discussion

### 6.1. Introduction:

Dental implant drills used for implant preparation are made of different materials including ceramic, zirconia and stainless steel (SS). Most of these materials do not have sufficient long-term wear resistance and cutting efficiency (Oliveira *et al.* 2012). Recently diamond-like carbon coating (DLC) has been added as a drill coating to improve cutting efficiency, increase wear resistance and increase drill hardness (Mends *et al.* 2014). The aim of this study was to determine the effect of a DLC coating on dental implant drill wear during implant site preparation.

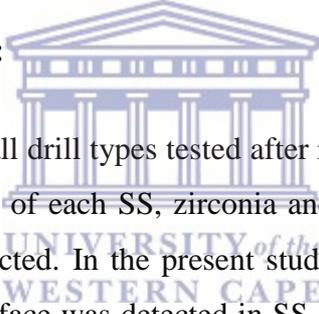
### 6.2. Effect of sterilization:

The effect of sterilization cycles on clinical performance of implant drills is still being debated. According to Harris and Kohles (2001), autoclave sterilization can lead to a reduction in the cutting efficacy of these drills. During sterilization procedures, water vapor produced can lead to an increase in the degradation process of the drill surface (Chacon *et al.* 2006). Sterilization may also result in corrosion (Allsobrook *et al.* 2011; Harris & Kohles 2001), reduction in the cutting efficiency (Cooley *et al.* 1990; Harris & Kohles 2001) and deformation in the sharp region of the drill (Jochum and Reichart 2000). Sartori *et al.* (2012) reported a loss of mass, increase in roughness and abrasive wear in the cutting area in zirconia, tungsten carbide film coated in a carbon matrix and SS drill types. In their study, sterilization and disinfection processes were not involved in the experimental design. In the present study, disinfection procedures and sterilization cycles were performed but its effect was not evaluated. Further research may be required to determine whether these factors had any significant effect.

### 6.3. Drilling time:

To the author's knowledge, this is the first reported study to measure the drilling time of implant drills with varying surface properties, after repeated use. In the present study, the first 4 groups (SS Adin, DLC Adin, SS Megagen and SS Strauman) repeatedly showed no statistically significant difference in drilling time between DLC coated and SS drills when measured after 5,10,15,20 drilling times. Unlike the other groups, Group 5 (SS Champions implants) showed an increase in drilling time with subsequent uses of the drill. This may be attributed to the different drill design of this group. These drills are tapered and have no flutes compared to the cylindrical shape of the other drills. In addition; the average drilling time was slower when compared to the other drills tested. According to the manufacture, Champions implants drills are recommended to be used five times at a low speed of 250 rpm. This may have contributed to the slow drilling times seen after 5 uses.

### 6.4. SEM descriptive analysis:



Signs of wear were observed for all drill types tested after repeated use. Batista Mendes *et al.* (2014) reported that after 40 uses of each SS, zirconia and DLC drills, in an *in vitro* study, different signs of wear were detected. In the present study, DLC coating delamination was observed whereas an irregular surface was detected in SS drills. This implies that more wear occurred in the SS drills. Oliveria *et al.* (2012) also reported signs of increased drill wear for twisted stainless steel drills compared to zirconia drills, after 50 uses. Significantly, Dos Santos *et al.* (2014) showed that drill deformation and roughness were directly proportional to the number of times the drills were used.

In this study, there was no difference between DLC coating and SS drills after repeated use. Most drills tested seemed to be effective up to 15 times with regards to wear resistance and cutting efficiency. However, stainless steel and DLC coating drills revealed signs of wear after being used 20 times. Damage and irregular cutting surface and higher tip wear were detected in stainless steel drills from group 1(SS Adin) and was noticeable after 20 drillings. No difference was found between this group (G1 SS) and SS drills from group 3 with regards to irregular cutting surface and tip wear after being used for up to 20 times. A correlation between drill wear and the number of drilling procedures was noticed. A significant finding was that delamination of DLC coated drills was observed after 20 drillings. This was seen

mostly affecting the drill tips as well as along the cutting edges. No evidence of loss of sharpness nor damage in cutting surfaces or wear tips were observed in SS drills in group 4 (Straumann), even after using them for 20 drilling procedures. The most affected drill in the current study appeared to be that of group 5 (Champions Implants). These drills displayed irregular surfaces and a higher tip wear of both edges. This may be attributed to the shape of the drill and using the drill beyond the manufacturer's recommendations. Champions implants recommend using these drills for not more than five times at low speed 250 rpm. In the current study, the drills were used for 20 times.

### **6. 5. Drill wear particles:**

Irrigation systems are used to prevent clogging of drill flute by bone chips (Kirschner & Meyer 1975; Koch 1976). Cited in (Tehemar 1999), and they might flush out drill particles that arise from drill wear. However this has not yet been reported. Of concern is that these wear particles may remain behind in the osteotomy site and may or may not affect bone healing. Whether this has any effects on osseointegration requires further investigation.

### **6.7. Drill Cost:**

The comparison between the DLC coated and SS drills, can also be denoted in terms of the drill cost. For the drills tested, the average current price in June 2017 of SS drills were four hundred Rands per drill (30USD - current) compared to eight hundred and forty Rands (62.5USD - current) per DLC coating drill. Since the drilling time for both types of drills were not statistically significant, one might consider the purchase of SS drills when drilling time and wear are taken into account.

### **6.8. Accuracy of osteotomy preparation:**

With regards to accuracy of osteotomy site preparation for the 2 drill types, this observation was not taken into account and requires further analysis to determine a significant advantage of one drill type over another.

## Chapter 7

### Conclusions

Based on the current study and its recognized limitations, the following conclusions can be made;

-Drill design, material, and speed significantly affect cutting efficiency, wear resistance and drill time. These factors should be considered during implant drill design and their combined influence evaluated during testing on bone tissue.

-No significant difference in drilling time was detected in groups 1,2, 3 and 4 between diamond-like carbon coated (DLC) drills and stainless steel (SS) drills after 5, 10, 15 and 20 times use except for group 5. This group could not be compared with the other groups, as the recommended speed of drilling and drill design was different to the other groups. In addition, the manufacturer's instruction did not allow the drills to be used for more than five times, as opposed to the 20 times in the current study.

-In the SEM images taken, most of the implant drills (groups G1, G2, G3, and G5) revealed signs of wear after 20 uses,

-DLC coatings on drills do not affect implant drilling time.

-All drills may wear leaving drill debris.

Further research is recommended to determine the clinical significance of the above findings.

## Chapter 8

### Limitations of the study

- A. Small sample size was tested.
- B. In Scanning Electron Microscopy (SEM), no measurable comparison could be made.
- C. The drill pressure and force was not standardized.
- D. The effect of the sterilization procedure on the wear rate or pattern of the drills were not taken into account.
- E. This was a laboratory-based study.



## Chapter 8

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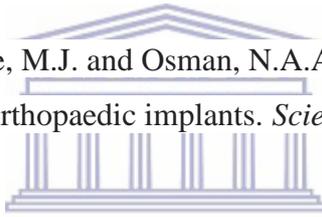
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