Experimental Study on Surface Quality of Hole and Biological Damage in Bone in Drilling

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Abstract— **Drilling of bone with a hard metallic drill is a common surgical procedure used in various contexts in orthopedics, neurosurgery, and dentistry. The performance of the process is based on the minimal invasion to the delicate bone tissue. Surface quality of the drill bit, the drilled hole and biological damage (death of bone cells) are the inevitable outcomes associated with the drilling process. Repeated use of surgical drills and other processes such as irrigation with saline solution and sterilization process causes wear of the cutting edges of the drill which can seriously affect its performance during operation. The aim of this study was to move a step forward towards minimally invasive surgical procedures in bones by investigating the effect of wear of surgical drill bits on postoperative outcomes. The surface quality of the drill was found to influence the surface of the drilled holes as well as the extent of biological damage around the drilling region. Worn drill produced poor surface quality of the hole and caused more cells death near the drilling region compared to a sharp drill.**

Keywords— **Bone drilling, surface roughness, surgical drills, bone necrosis, biological damage**

I. Introduction

Bone drilling is routinely performed for the treatment of fractures for fixation devices and other related orthopedic diseases and bone replacements. Bone drilling is performed either a using motorized hand-held surgical drill and is one of the most discussed procedure in the published literature [1]. Drilling is a complex mechanical operation in which a significant amount of heat may generate due to the shearing of the materials with high speed. In addition to the heat generation in the cutting region, large drilling forces may also generate which may subject overstressing the delicate bone tissue [2,3]. Factors influencing performance the drilling process in bone are the drill speed, drill size, speed of penetration and drill geometry. Current research is largely focused on the measurement of thrust forces and temperatures [4, 5]. Unfortunately, few studies were focused on measurement of delamination, cracking and biological damage [6-8]. One of the key parameter influencing the performance and associated safety in drilling into the bone is the surface quality of the drill bit. Sever studies have reported thermal osteonecrosis and micro fracturing of bone and breakage of the drill as a result of drilling [9, 10]. The research on the topic is still going and largely focused on the determination of optimum drilling parameters for safe and efficient drilling in bone. One of the drilling technique, known as ultrasonic drilling (UD) or vibrational drilling (VD), has recently been tested for minimal invasive drilling in bone [11]. UD has been found to significantly minimize the drill penetration force, bone temperature, and torque when used along with control drill speed, irrigation of the drilling site (cooling) and speed of penetration (feed rate). The technique has also been found helpful in inducing fewer microcracks surrounding the hole in bone tissue compare to conventional drilling. The technique was found to cause less number of cell death surrounding the drilling region compared to CD.

One of a unique feature of using bone surgical tools in bone cutting is that it should not provoke injury to the delicate tissue, nerves, and vessels. Structural and thermal damage induced in bone tissue as a result of drill penetration in delicate structure of bone can compromise the remodelling process around the implant. Researchers have used histology to evaluate the level of necrosis caused by high speed drilling in bone. The bond between the drilled hole and implant are critical for the osseointegration and healing. Blunt edges of a surgical drill bit significantly reduce its cutting ability and accuracy as well as excessive generation above a thermal threshold level for necrosis [12] and large drilling forces and resistance [13]. In addition to thermal and mechanical damage in bone, the cutting edges of a worn drill can be fractured and break during a surgical incision [10]. Although the link between the drill wear, force, torque and temperature in a bone-drilling process is well established, to the authors knowledge, no study addressed the effect of drill wear on cell viability in bone. This study evaluated and discussed the effect of drill quality and speed of penetration on the surface roughness of the hole as well as death of viable cells near the cutting region. We believe that this study is a step forward towards minimal invasive surgical procedures in bone. A comparative analysis on the surface roughness of the drilled hole and cell death is performed using a sharp drill (SD) and a worn drill (WD).

II. Materials and methods

A. Bone Specimen

Cortical bone excised from the middle part of the femur and tibia of freshly slaughtered bovine (cow) were used in drilling tests. The selection of bovine was made since it has been reported to have similar structural composition, mineral content, healing characteristics and mechanical properties as those of human bone [1]. The mid-diaphysis was cut from the main femoral shaft immediately after the animal was slaughtered. The average thickness of the cortical wall of the cut specimens was 8 mm. The specimens used in the tests were free from any significant osteopenia and musculoskeletal disease. For histology examination, the drilled specimens were fixed in 10% formaldehyde solution for 16 hours after the drilling procedure followed by decalcification in a solution of 40 ml 65 vol % nitric acid, 20 ml 10 vol% formaldehyde and 340 ml distilled water for 48 hours. Authors expect that fixation and decalcification process would not affect affect the tissues.

B. Drilling equipment and Roughness Measurement

Drilling tests were performed using a vertical drilling machine originally developed for conventional and vibrational drilling in bone. Bone drilling system used in experiments is shown in Fig. 1(a). Drilling tests were carried out using standard two-flute 4.8 mm surgical drills (Orthofix, Italy). Different experimental equipment namely, Olympus BX53 system microscope, Scanning Electron Microscope (SEM) and Alicona InfinteFocus microscope were used to measure structural and biological damage in drilled holes and surface profilometry of the surgical twist drills and drilled holes. In this study, roughness of the cutting lips of the drills was measured using an OGP Flash 200 Optical measuring microscope and Alicona Infinite Focus microscope (see Fig. 1). For this purpose, the roughness profile was obtained along the cutting edges (cutting lips) and chisel edges of the drills. The Zygo interferometry instrument NewViewTM 5000 series was used for surface roughness of the drilled holes. Two surgical drill bits namely sharp drill (SD) and worn drill (WD) with known numbers of drilled holes and average values of roughness were used in the drilling experiments (see Fig. 1c). The drilling cite was kept hydrated during drilling process by gentle spray of water in the drilling region. The drilled holes were cut into halves with a hacksaw to expose the surfaces for roughness measurements. The surface roughness of the drilled hole was measured along the drilling direction shown with a dashed line in Fig 1(b).

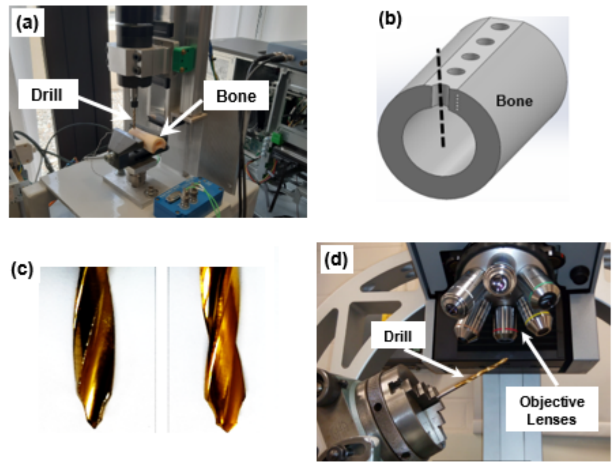

Fig. 1 (a) bone drilling system with necessary attachment for force and temperature measurements, (b) bone specimen for drilling, (c) surgical drills, (d) surface roughness measurement system for drills.

III. Results

A. Roughness Measurements

Surface roughness parameter (R_a) is defined as the arithmetic average deviation of the surface valleys and peaks expressed in micrometres. The average roughness along the cutting edges of SD and WD were measured and found 1 μm and 5 μm respectively. The surface roughness of the holes drilled using SD and worn drill WD are shown in Fig. 2. Figure 2 also shows surfaces roughness of the drilled holes visualised using SEM. Visible dents can be seen in the SEM image showing a hole drilled using a WD. The results indicated that SD produced better surface quality of the hole compared to the WD as shown in Fig. 3. Similar results were obtained using different drill rotational speeds as well as speed of penetration. Better surface quality obtained using SD was due the improved cutting of chips in the drilling zone. The aforementioned results of the surface roughness of the hole may be useful for the development of contact models between the bone and screws using analytical and numerical methods in future.

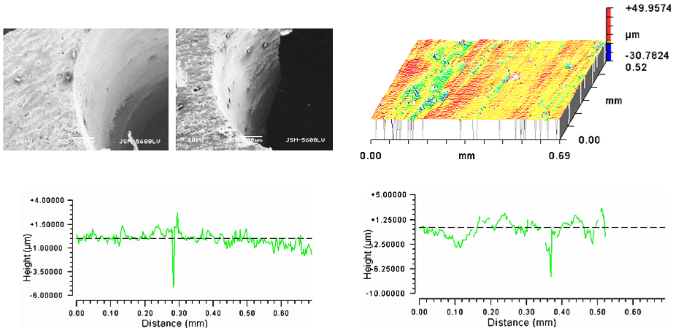

Fig. 2 Top row: surface quality of the holes drilled with SD and WD (left – SEM images showing drilled holes, right – surface roughness plot obtained using Zygo interferometry. Bottom row: Left – surface roughness profile of the hole using SD, right – surface roughness profile of the hole using WD.

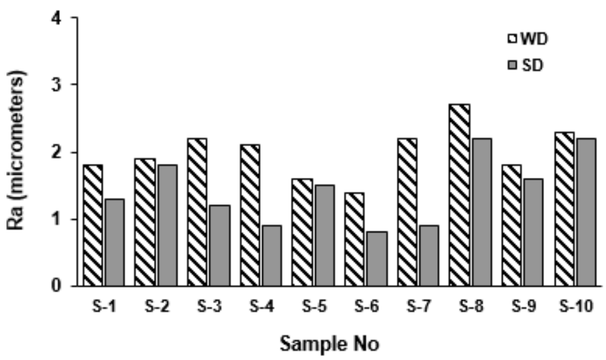

Fig. 3 Surface roughness of the drilled holes in 10 samples.

B. Histology and Cell Damage

A representative histology image showing viable osteocytes (living bone cells) within the lacunae is shown in Fig 4. The images presented below show some artifacts due to decalcification as well as fixing the tissue in some chemicals for highlighting bone cells as well as clarify the microstructure of the surface of the bone. The dark spots, indicated by the arrows in the image, shows that the cell is intact and not resorbed in the bone tissue. The locations of viable bone cells lying inside the lacunas and empty lacunas, indicating loss of the cells, are shown with black arrows and circles, respectively. The cells were observed approximately in the middle section of the cortical thickness. Although not studied here, Haversian canals are enclosed with rectangles in the image. Only few osteocytes, lacunas and Haversian canals are highlighted in the histology image. In addition, only a portion of the section surrounding the cut surface is shown for better visibility. The absence of osteocytes in the lacunae (encircled) indicating death of the cell is considered biological damage in this study. One of the limitation of the current study was that the drilling region was not checked for any cell damage before the drilling process and this study will be conducted in future. The drilling region will be drilled with very slow speed to confirm that cells were intact before drilling with high speed.

A comparison of the damaged cells (represented as cell death) resulting from drilling using a SD and WD is provided in Fig. 5. The cell death, measured in percent, was calculated approximately at the middle of the depth of the hole. The calculation of cell death was based on the drilling in the direction perpendicular to the longitudinal axis of the bone. A quantitative assessment revealed more loss of bone cells using a WD compared to a SD using similar drilling parameters and conditions. Each calculation pertinent to the cell loss was calculated in three different holes using similar drilling conditions and the average values along with error were plotted. Examination of histology images, taken along the depth of the hole, revealed more cell death at higher depths of drilling. This may be due to the increased level of drilling force, torque and bone temperature produced at higher depth of drilling. As expected, the maximum temperature recorded was 50ºC and 45ºC using a WD and a SD, respectively, at a depth of 3 mm. Similarly, the maximum temperature recorded was above 70ºC using a WD in the section closed to the exit of the hole. Interestingly, the cell death was noticed to decreased away from the cut surface in the radial direction regardless of the type of the drill used. The authors would like to carry out experiments such as histochemical analysis of Lactate Dehydrogenase (LDH) activity to measure cell viability in future studies.

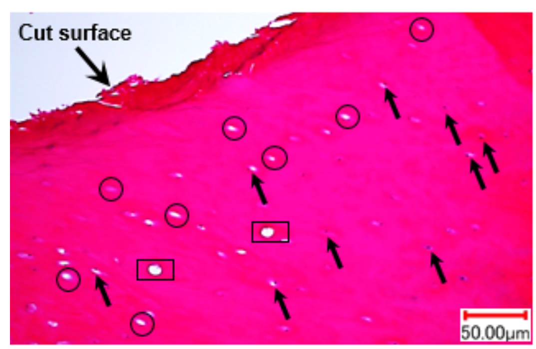

Fig. 4 Representative histopathology plot showing viable bone cells surrounding the cut surface (drill speed – 2000 rpm, feed rate – 30 mm/min).

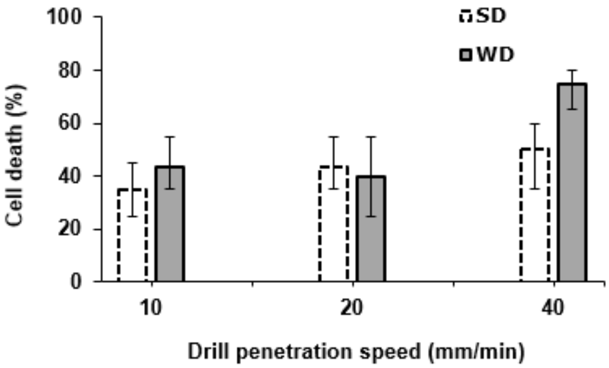

Fig. 5. Effect of drill quality on the cell death (drill speed – 2000 rpm, feed rate – 30 mm/min).

IV. Conclusions

The effect of surface quality of surgical drill on the roughness of the drilled hole and biological damage (death of cells) in bone was studied. Worn drill was found to produce rougher surface of the hole compared to a sharp drill. Worn drill induced more biological damage in the bone compared to a sharp drill for similar drilling conditions. Further studies may be carried out to evaluate the strength of the bond between the implant and the bone when a blunt drill is used in drilling the bone in routine surgical procedures.

Acknowledgment

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Conflict of Interest

There is no conflict of interest.

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