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Research Article

Alteration of the Thrust Force Versus Number of Drill Bit Usage in Cortical Bone Drilling

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Abstract

Background: Bone drilling is a common step in orthopedic surgery. Thrust force is one of the most important parameters that can influence the quality of bone drilling. The number of drill bit usage has some limitations and it can affect the quality of bone drilling.
Objectives: The aim of this study was to investigate the limitations of drill bit usage number to increase the bone drilling quality.
Materials and Methods: Two mid-diaphysis sections of male human cadaveric femora were prepared. Five orthopedic drill bits were used to identify the effects of the usage number. An orthopedic hand piece was attached to the dynamic testing machine. The spindle speed and feed rate of the drill bits were 900 rpm and 0.5 mm/s, respectively. Drill bit usage of 0, 20, 40, 60 and 80 were prepared for scanning electron microscopy (SEM). SEM images were taken to illustrate physical changes on the cutting surfaces of the drill bit.
Results: There was an increase in the thrust force by increasing the number of drill bits usage. Irreversible physical damages were observed in drill bit point angle, frank face, and flutes of drill bits.
Conclusions: The number of drill bits usage has limitation. Drill bits that are similar to the ones of the current study are better to be used no more than 55 times.

Keywords: Drill Bit Usage, Thrust Force of Bone Drilling, Cortical Bone Drilling, Bone Drilling Parameter

1. Background

Bone machining including bone cutting, bone rimming, and bone drilling, is a crucial process because of the high number of defects caused in bone such as in trauma, tumors, and fractures. Bone drilling is a common step in orthopedic surgeries. It generates heat due to the existence of friction between drill bit and bone, and also chips and the drilled hole wall (1-4). The heat generated from these operations may result in thermal necrosis. Since thermal necrosis generally has negative impact on the outcome of drilling procedure, bone temperature must be kept below the damaging threshold. Osteonecrosis will reduce bone strength and cause loosening of internal fixation (5, 6). Eriksson and Albrektsson (1) indicated that osteonecrosis occurs in living rabbits when the bone is heated to 47°C for one minute. Other studies have suggested that if the temperature exceeds 55°C for longer than 30 seconds, irreversible damages occur in the bone (6). Many researchers have studied the effects of various parameters on bone temperature (7-13). Damage to the bone, caused by drilling, is not limited just to excessive heat generation. Thrust force is another factor that can also damage the bone under treatment (14, 15). Thrust force is the force applied to the drilling hand piece by surgeons (14, 16). In cortical bone drilling, a wide variety of parameters influence the final temperature of the bone. According to the literature, these parameters are divided into three groups; 1) drill bit parameters; 2) bone properties; and 3) bone drilling process parameters. The drill bit diameter, point angle, helix angle, and initial drill bit temperature are categorized in the first category (17, 18). Gender, bone density, and age are included in bone parameters (11). Spindle speed (rotational speed of drill bit) and feed rate (linear speed of drill bit perpendicular to the bone) are important factors in the third category (6, 19, 20). Moreover, there are many parameters that can affect the shape and magnitude of thrust force in the bone drilling process. These parameters are drill bit diameter, drill bit number of usage, point angle (angle of drill bit head), helix angle, feed rate, spindle speed, and bone mineral density. The drill point design consists of the helix angle, point angle, relief angle and clearance. It seems that drill bit point angel and drill bit diameter are the most important parameters of drill bit design. With respect to the kinematic of bone drilling, rotational speed and feed rate are the most important factors (9, 11, 21). Some parameters like drill bit temperature, using of cooling systems and primary drilling are theoretical and have not been used practically (11, 22, 23).

2. Objectives

This study aimed investigating the effects of the number of drill bit usage, in a real orthopedic surgery, on the thrust force, during the bone drilling process.

3. Materials and Methods

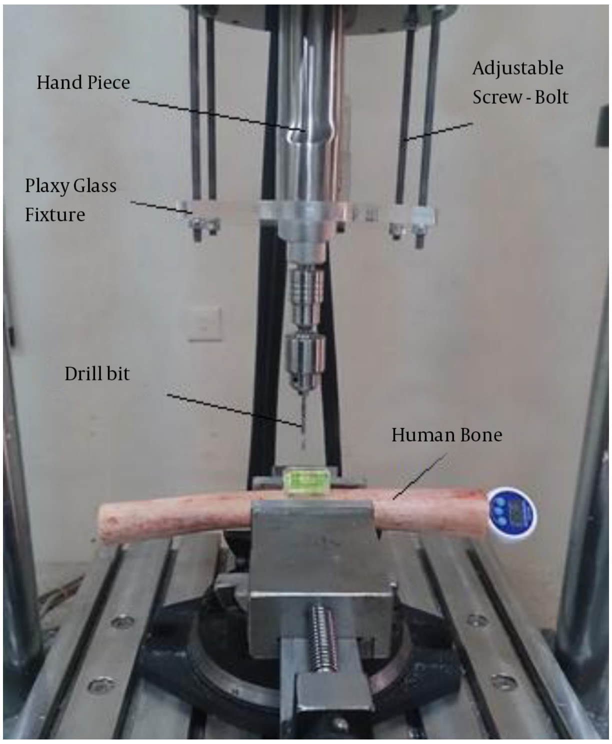
In this study, animal and human cadavers as well as a drilling hand piece attached to the dynamic testing machine were employed. Orthopedic drill bits were used in order to closely simulate the experimental tests. The thrust force of each drilling process was recorded by a load cell. From one animal, bone samples were obtained from a local slaughterhouse shortly after the animal's/animal death. No animals were sacrificed specifically for the purpose of the current study. A total of 10 samples were prepared, each specimen accommodating approximately 10 drilled holes. The specimens were maintained in saline solution and kept in a frozen state at -20°C according to the guidelines provided (24). Prior to experimentation, the specimens were rasped to flatten the surface. The average thickness of cortical wall was about 6 - 9 mm; mid-diaphysis of bovine femora (2 - 3 years old) with the approximate height of 100 mm was used. The average thickness of cortical wall was about 8 - 12 mm. Moreover, two mid-diaphysis sections of male human cadaveric femora (25 years old) with the approximate height of 70 mm and bone mineral density of 1.508 g/mm^2 were used in this study. An Iranian orthopedic drilling hand piece which is being used in about 320 hospitals in Iran was utilized in this study. This hand piece has a dimmer for adjusting the spindle speed from zero to 900 rpm. The maximum spindle speed was used in this investigation. The hand piece consists of a chargeable battery; however, the fully charged hand piece was used in this study. Drilling hand piece connected to the dynamic testing machine with a plexiglas is shown in Figure 1. To adjust the perpendicularity of the drill bit, four screws and bolts were used (Figure 1).

A dynamic testing machine (Zwick/Roell, Germany, 2004; available in biomedical engineering faculty) consisting of an accurate linear variable differential transformer, with accuracy of 100 microns and resolution of 10 microns, was used. All the forces were detected by a 0.5 KN load cell, which was calibrated with an accuracy of one percent of its full capacity. Six stainless steel orthopedic two-flute drill bits with diameters of 3.2 millimeters were used in this study. The point angles and helix angles were 80 and 35 degrees, respectively. Five drill bits were chosen to investigate the effects of the number of usage on the drilling process. Drill bit with 0, 20, 40, 60 and 80 times of usages were chosen for scanning electron microscopy (SEM). Moreover, a drill bit was chosen to investigate the thrust force in bovine bone samples. All the drilling processes were studied using displacement control and the thrust force was recorded during each drilling process. The tips of the drill bit were initially kept 5 and 3 mm over the surface of bovine and human samples, respectively. Drilling depth was defined as 10 and 7 mm, and the controller descended drill bits 15 and 10 mm through the bovine and human bone, respectively. These numbers were deduced from the thickness of bovine and human samples to have uniform drilling depths. As seen in Figure 3A, the feed rate was adjusted to be 0.5 mm per second and kept constant in all the tests. The resting time, which is defined as the time between entrance and exit of drill bit, was considered to be zero and the exit rate was 3 mm/second. With these definitions, the durations of the drilling processes were 35 and 23.3 seconds for bovine and human cadaveric bone samples, respectively. All the data were analyzed by ANOVA test.

4. Results

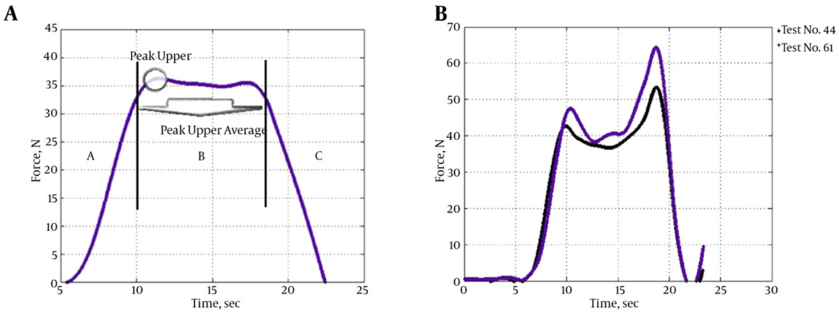
A typical thrust force versus drilling time, which was recorded in this research, can be seen in Figure 2A. The positive ramp from zero to the peak upper is considered as drilling engagement, which is denoted as "A" district. The approximate horizontal line between part A and part C, which is indicated as exit portion, is considered as the drilling part (25). According to Figure 3A, there is a circled

Figure 1. Experimental Setup Test



Hand piece is connected to the plexiglas fixture and attached to the dynamic testing machine.

Figure 2. Curves



C

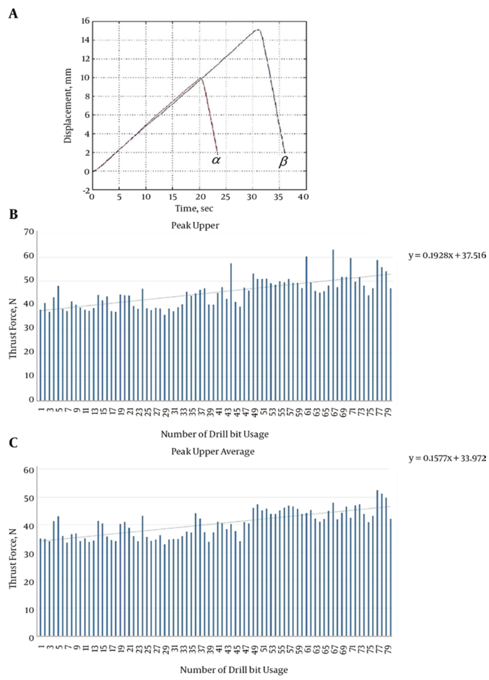
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1
2	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
3	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
4	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
5	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
6	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
7	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
8	0	1	0	0	0	1	0	0	0	0	1	1	0	1	1	1
9	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
10	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
11	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
12	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
13	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
14	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
15	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
16	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0

D

A, Typical thrust force recorded during time of bone drilling, process from zero force to peak upper, part A, is the drilling engagement, peak upper occurs right after part A, Part B consisting of main drilling district, is named as peak upper average, Part C is the last part of the drilling process, named as drilling exit; B, turbulence in the second phase of drilling process, drilling phase, in the drill bit usage numbers of 44 and 61; C, 16 × 16 symmetric, squared with zero diagonal matrix of P value, where 80 data is divided into 16 groups; D, remaining chips in the blunted flutes of drill bits which were used most.

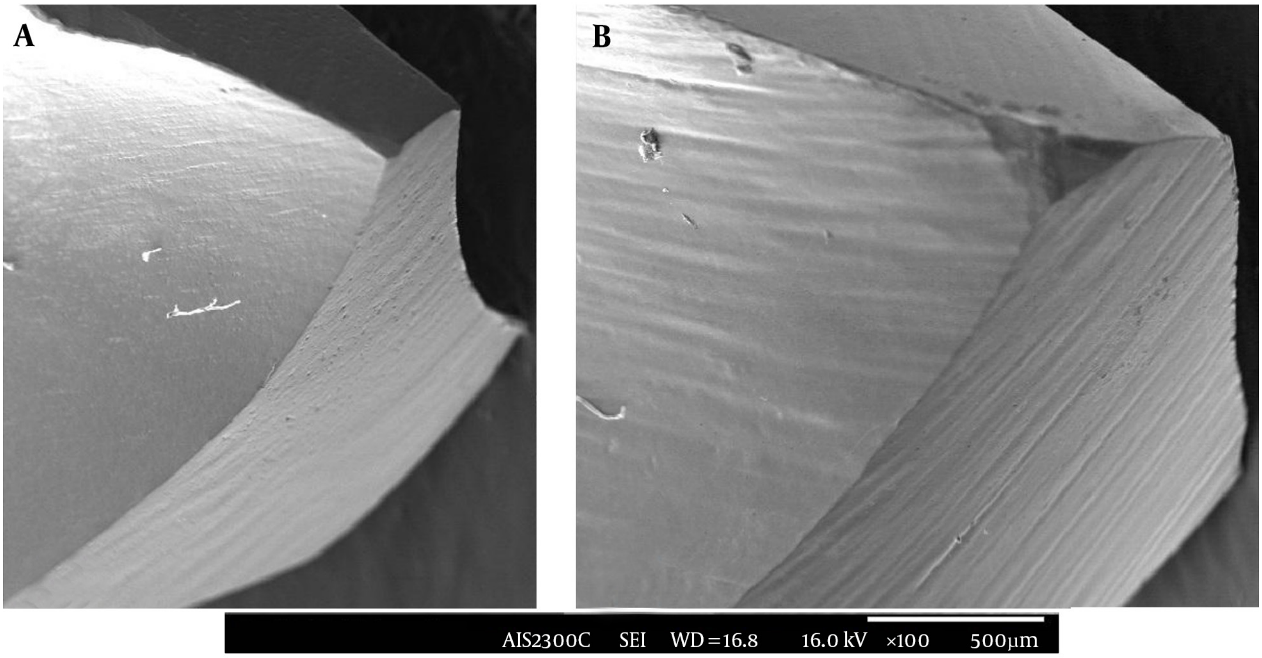
part known as peak upper, which occurred right at the beginning of part B. The whole portion of part B is indicated as the maximum part of the thrust force, which was named as peak upper average in this study. Figures 3B and 3C represent 80 bar curves for peak upper and peak upper average, respectively. Each bar illustrates thrust force according to the number of drill bit usage. It is clear that Figures 3B and C belong to the drill bit usage of 80. For the SEM analyses, 200 drilling processes were performed to have drill bits with usages of 20, 40, 60 and 80 times. A brand new drill bit sample was also used for the SEM analysis. Eighty data from Figures 3B and C were classified in four groups shown in Figure 5A. One-way analysis of variance (ANOVA) was applied between each two group. Data set showed the P values of each test. It was shown that there was no significant difference between 0 - 20 and 20 - 40 groups, as well as 40 - 60 and 60 - 80 groups. Figure 4 compare SEM images of an intact drill bit and 80-times-used drill bit. In two-flute drill bits, there are four cutting edges. Right-handed rotating drill bits have two activated cutting edges. Drill bit point angle is the first and the last point of drill bit, which touches a bone. Therefore, it is the part of drill bit with most contact time during the drilling process. The flank face of a drill bit has a direct contact with a bone. Flutes have the most responsibilities for chips transportation (9). Some permanent damages to the specifications mentioned above can be seen in Figure 4. Peak upper and peak upper average of first 20 drilling processes on human cadaveric and bovine samples can be seen in Figure 5B.

Figure 3. Drill Bit Usage



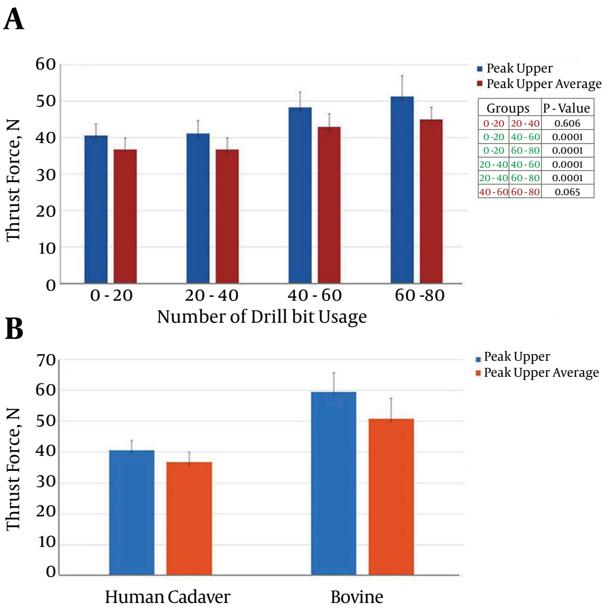
A, Displacement time curves for a typical drilling process for: α) human cadaveric samples and β) bovine bone samples; B, thrust force bar curves versus number of drill bit usage according to the maximum point, i.e. peak upper values; C, thrust force bar curves versus number of drill bit usage according to the horizontal line named peak upper average (see Figure 2 A).

Figure 4. Scanning Electron Microscopy Images With Magnification of 100



A, Intact drill bit; B, drill bit after 80 times of usage.

Figure 5. Thrust Force



A, Eighty data drill bit usage were classified in four groups, the Tabulation denotes the significant groups; B, thrust forces, peak upper and peak upper average (see Figure 2A) of first 20 drilling processes of human cadaveric and bovine samples.

5. Discussion

Superficial layers of long cortical bones are more calcified than the deep regions of the cortex. With respect to the microstructure of superficial layers of cortical bone, where initial contact of drill bit and flank face occur (15, 26), right after the primary phase in Figure 2A, a relative maximum occurs. With this deduction, peak upper and peak upper average have a little bit difference. The average of all 80 peak upper thrust forces data (Figure 3B) was 45.3 N with the standard deviation of 6.2 N, while the average of all 80 peak upper average thrust forces (Figure 3C) was 40.4 N with the standard deviation of 4.9 N. Figures 3B and C illustrate proportional rise in thrust force of drilling process, as the number of drill bit usage increases. The slopes for the peak upper and peak upper average were 0.193 and 0.157 N/usage, respectively. R-squared for each fitting was almost the same. Figure 5b shows the significant difference between thrust force of human cadaveric bone and bovine bone samples. This can be due to the greater density or bone mineral density (BMD) of bovine bone samples compared to human cadaveric bones (1.508 g/m^2). To evaluate the critical usage number, 80 data of thrust force were divided into four groups. Based on Figure 5A, critical usage number was found to be somewhere between the 20 - 40 and the 40 - 60 groups, due to the happening of first significant point. To illustrate the significant point more accurately, 80 data were divided into 16 groups. One-way ANOVA tests were performed between every two groups and a 16 × 16 matrix was resulted (Figure 2C). The matrix Mij was symmetric and all the Mii were zero. Mij changed to "0" if P values were more than 0.05 and "1" if less than 0.05. In every row, the first "1" is the significant point. For example, in third row, the first "1" occurs in the 10th column. It means that the significant point happened between the usages of 50 and 55. The most frequent significant point in various rows happened in the 11th column. In some tests, for instance in test numbers 44 and 61, the approximate uniform thrust force (Figure 2A) had some fluctuations in their second phases (Figure 2B), i.e. in drilling phase. As the usage number increased, drill bit point angle, flank face and flutes got blunted and drilling chips remained in the flutes. These can rise the drill bit temperature as well as the bone temperature (11). Figure 2D shows the remaining chips in the flutes of the drill bit.

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