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Experiment Investigation of Hole Accuracy and Surface Roughness in Femur Bone Drilling using Different Parameters

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Abstract. Success indicators in bone drilling include clean, good accuracy drilled holes without damage at the surrounding tissue. This study investigates the influence of cutting parameters in bone drilling against hole accuracy (enlargement diameter, circularity error, and cylindricity error) and surface roughness (Ra). A series of bone drilling experiments was carried out using femur bovine bone and without irrigation. Variations of drill type (high speed steel and coated and uncoated carbide) and cutting speed (19 m/min and 94 m/min) were used as input variables, while the feed rate (0.025 mm/rev) was constant. It was found that coated carbide drill results minimum magnitude on all machining responses. Type of tool gives significant effect on diameter enlargement and surface roughness, yet not on circularity and cylindricity errors. The range of cutting speed evaluated does not give significant effect on any surface integrity measures.

Introduction

Damage of bone tissue due to the bone drilling process during orthopedic surgery is a major issue of concern. Incision and scraping of the tool against bone tissue during machining process might result increased heat and also injury to the bone. Increase of excessive heat and severe injury conditions deteriorate the success of surgery and can cause prolonged healing time [1-4].

Bone drilling process in orthopedic surgery actually has something in common with the drilling process conducted by the manufacturing industry. The fundamental difference between them lies only in the workpiece material. Therefore, to assist in analyzing the process of the bone drilling, one can use approaches in the theory of metal cutting [5,6]. Bone is a living tissue, so that when seen as a workpiece material, it certainly has higher sensitivity and dynamics compared to non-bone materials used by the manufacturing industry. Clean and accurate drilled holes without damage at surrounding tissues are the desired outcome of the bone drilling process [4]. Performance of the drilling process and the level of bone tissue injuries can be represented using these indicators. As in metal cutting, they are strongly influenced by machining conditions of the drilling process [3]. Although there is still disagreement regarding results obtained, many studies of bone drilling have been conducted at variety of machining conditions. Excessive heat and damage during bone drilling can be caused by large forces, use of the wrong drill, inappropriate selection of cutting speed and feed rate, as well as other machining conditions [1-6].

This study determines the influence of cutting parameters in drilling the bone against the dimensional quality and surface finish of the drilled holes. Input variables in this study are drill and cutting speed. Meanwhile, the response of bone drilling results to be measured is the holes accuracy (enlargement diameter, circularity and cylindricity error) and surface roughness (Ra).

Experimental

Bovine bone has similar properties to human bone [7], so bovine femur was used as a workpiece in this study. Both proximal and distal ends of the femur were removed and then cut into two parts. Two holes were made at a position close to both ends of the specimen and were used as guide-pins on the jig that was prepared previously (Figure 1). Three drill types (high speed steel (HSS), uncoated carbide, and coated carbide) with 6mm diameter, two flutes, and 118° point angle were used as cutting tools. The process of through-hole drilling at the bone was carried out in CNC Milling Machine LEADWELL MCV-610 CR with two variations of cutting speed (19 m/min and 94 m/min) and constant feed rate of 0.025 mm/rev. No coolant was used during the drilling process.

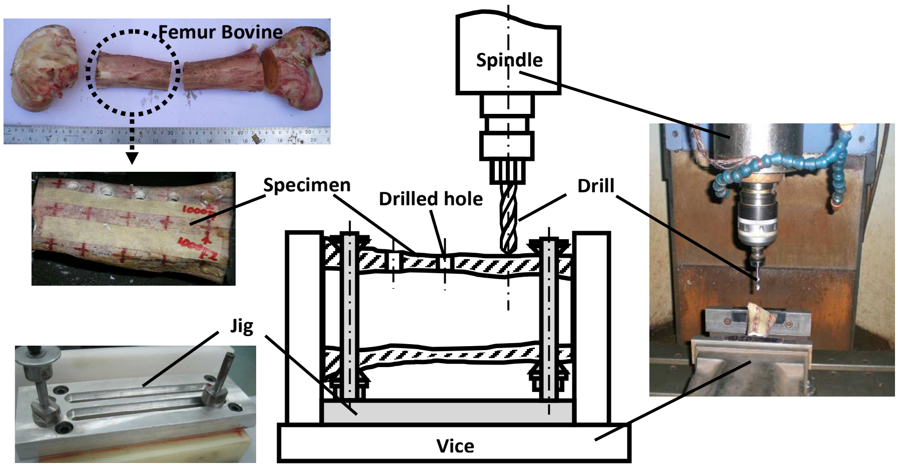

Figure 1 Figures and schematics of experimental set-up

Hole accuracy which includes enlargement, circularity, and cylindricity errors were measured using coordinate measurement machine (CMM) Mitutoyo 810 KN. Three positions towards the hole depth were measured. At each measurement position, twenty measuring points along the circumference of the hole were taken at equal distance between the measuring points. The difference between average diameters of the measured holes and diameter of the drill is the enlargement. Shifts in center coordinate (X-Y axis) of the second measurement position from center coordinate of the first measurement position and the center position shift between third position and second position are the cylindricity error. Circularity error was the average difference between mean radius of the smallest and the largest radii at each position measurement of the radius from the axis of the drilled hole. Surface roughness (Ra) was obtained from the average of measurements of transverse surface of the cylinder wall hole using surface profilometer Accretech Handysurf E-35 B at three different positions. Five repetitions with cut-off length (λc) = 0.8 mm were done at each position of surface roughness measurement. Observation using optical microscope confirmed that the stylus of the surface profilometer did not leave trace on the measured bone surface, indicating no bias in the measurement. Analysis of the significance effect of the input variables was made using analysis of variance (ANOVA) with a confidence level of 95%.

Results and Discussion

The results of the experiments are shown in Figure 2. Drilling using coated carbide drill was capable of producing the smallest magnitude on all responses. Use of high cutting speed (94 m/min) did not always provide minimum magnitude. Enlargement that occurs was in the range of 1-8 µm over the drill diameter. The smallest drilled hole obtained was from the use of coated carbide drill at cutting speed of 19 m/min, while the largest diameter was when the cutting speed was 94 m/min using HSS drill. For circularity error, larger magnitude was obtained from the setting at low cutting speed (19 m/min) in all types of tools with error range of 90-357 µm. Setting at high cutting speed (94 m/min) causes error of 75-99 µm. Similar trend was obtained for cylindricity error. For surface roughness (Ra), range of 0.4-0.6 µm was produced, which means the surface finish was very fine, within finish machining range if viewed as common industrial workpiece [8].

Table 1 presents the results of analysis of variance (ANOVA) of all responses selected in this study. Effect on all responses incurred by drilling parameters is not significant, except for cutting tool type which significantly affects diameter enlargement and surface roughness on the drilled holes.

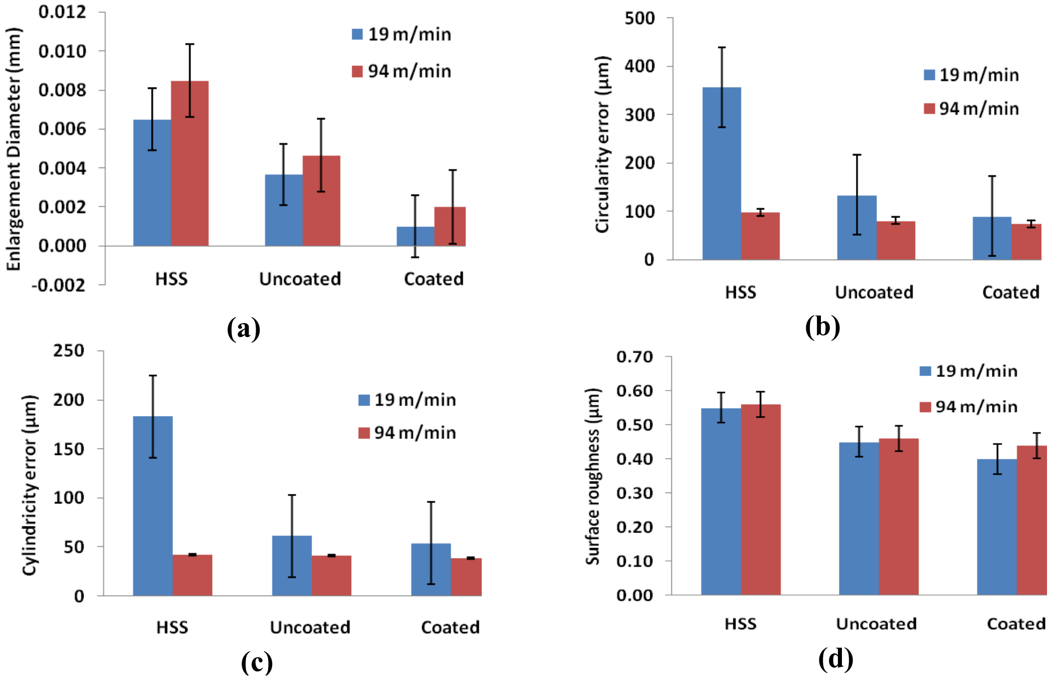

Figure 2 Effect on the machining responses (a) enlargement diameter, (b) circularity error, (c) cylindricity error, and (d) surface roughness

Table 1 ANOVA calculation for all responses.

Source	*Sum of square*	*Degree of freedom*	*Mean square*	*F*	*P-value*	*F crit*	
Enlargement diameter							
Cutting speed	2.67E-06	1	2.67E-06	16.0	0.057	18.5	not significant
Tools	3.61E-05	2	1.81E-05	108.4	0.009	19.0	significant
Circularity error							
Cutting speed	17908.81	1	17908.81	2.1	0.284	18.5	not significant
Tools	24129.81	2	12064.91	1.4	0.414	19.0	not significant
Cylindricity error							
Cutting speed	5161.728	1	5161.728	2.0	0.290	18.5	not significant
Tools	5402.086	2	2701.043	1.1	0.485	19.0	not significant
Surface raughness							
Cutting speed	0.0006	1	0.0006	4.0	0.184	18.5	not significant
Tools	0.0196	2	0.0098	65.4	0.015	19.0	significant

Effect of tool type on diameter enlargement of the drilled hole is likely caused by the differences in dynamics of the drill material. Rotational speed, geometry, and material of drill are factors that can affect natural frequency of the drill during machining, eventually affecting the diameter and the accuracy of drilled holes [12-16]. For surface roughness (Ra) where coated carbide drill resulted the finest, it might be due to its minimum heat and friction coefficient [9,10].

Some contrasting results of this study with previous studies on common workpieces exist, in particular the influence of cutting speed. It was noted that increase in cutting speed will result in decline of cutting force due to increased heat that softens the workpieces [8,11,12]. Apparently, it is not the case for bone machining. Other references are limited to analyze further the effects on other machining responses. It is recommended that further study needs to be conducted to address these and other aspects in machining of bones for less invasiveness of the surgery.

Conclusions

When particular drilling of bovine femur was conducted using different tool types at two different cutting speed, it was found that in terms of surface integrity responses measured on the drilled holes, type of tool significantly affects diameter enlargement and surface roughness. Its effect on other surface integrity measures was not significant. It was also found that cutting speed (or at least the range of cutting speed evaluated) does not affect the surface integrity measures.

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