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Effect of Changing Point Angle and Helix Angle Values of Drill Bit on Bone Drilling Simulation

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Abstract: Orthopedic surgery treats disorders of the bones and soft tissues, especially in cases of accidental fractures. One method of fracture healing is to place plates and bolts in the bone. However, the drilling process for plate installation can cause an increase in temperature around the drilling area, which risks causing necrosis in the bone. This study aims to examine the effect of drill bit design on the temperature generated during bone drilling. Modifications to the point angle, helix angle of the drill bit can reduce the temperature during drilling. The results of this study suggest that optimizing the drill bit design can reduce the risk of necrosis and improve drilling efficiency, which can accelerate the healing process of broken bones.

Keywords: Orthopedic surgery, bone fracture, drilling temperature, drill bit design, necrosis.

1. Introduction

Drilling is a machining process with the aim of making holes in the workpiece [1]. The drilling process occurs when a cylindrical drill bit rotates about the workpiece [2], creating a scraping process [3] and producing flakes called chips through the helix groove of the drilling tool to the outside of the hole [4]. The shape of the hole resulting from drilling can be determined by the state of the tool tip or the geometry of the tool blade [5]. Therefore, to obtain the desired drill hole quality, it is necessary to match the cutting parameters with the machining conditions used. This needs to be a concern considering that the quality of the results of a machining process is influenced by many factors. All aspects involved in cutting operations contribute to the quality of machining results. In general, these aspects include cutting parameters, cutting tools, workpiece material and cooling system which includes the cutting fluid and cooling strategy used. The suitability of all aspects of cutting operations will have an impact on effectiveness and efficiency in production activities [6].

In the orthopedic field, bone drilling is an important part of the surgical methods commonly performed for internal fixation in the treatment of fractures. The main purpose of bone drilling is the creation of holes to insert screws to immobilize the fractured part [7]. Pen placement requires bone drilling for the insertion of metal plates and bolts for internal and external fixation. The drilling process will generate frictional force between the tool blade and the bone surface. The friction process generates heat which is caused by the quality of the bone and the parameters involved in the surgical process [8]. Broken or fractured bone repair surgery is usually performed by installing a Dynamic Compression Plate (DCP) with bone bolts. Before attaching the bolts, the orthopedic doctor will perforate the bone with a drilling process. During the process, due to the cutting force and friction force between the drill bit and the bone, it will cause an increase in temperature in the bone around

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the hole. If the increase in bone temperature exceeds the allowable limit, it can cause bone cells to die due to loss of blood supply, also known as bone necrosis or osteonecrosis. The presence of osteonecrosis will slow down fracture healing. In addition to osteonecrosis, bone drilling also has the risk of drill bit breakage while drilling due to errors in drilling procedures and parameter selection [9] Friction between the bone and the rotary drill bit induces an increase in temperature in the drill bit and the drilled bone. This can lead to drill bit deformation as well as bone necrosis, which adversely affects the fracture healing process. So it is important during the drilling process to pay attention to the drill bit geometry, drilling rate, drilling speed, and cutting force generated by the drill bit [10].

2. Materials and Methods

This research uses Autodesk Inventor 2015 software for drill bit modeling, while DEFORM-3D software is used for the simulation process. Furthermore, Minitab 17 software was used as a tool in data analysis. Based on previous research conducted by Yusoff in 2018, it is stated that the increase in drilling temperature can be reduced by using a point angle value between 110° to 140° and a helix angle between 5° to 30° [11] while other researchers, namely Lee in 2018, generally recommend a point angle of 70°-90° or 120°-140°, as well as a helix angle of 24°-36° [12]. Based on previous research, there is no agreement on the best tool geometry value to be used in the bone drilling process. Therefore, research on the design of the drill bit geometry will continue.

In this research, the diameter and web thickness of the drill will be kept constant at 3.5 mm and 0.8 mm. Based on the geometry determination that has been done, 4 different drill designs will be made according to the combination of point angle and helix angle values. All designs will be created using Inventor 2015 software. To continue the research to the next stage, the thing that needs to be prepared is the determination of the value of bone material properties. Because the DEFORM 3D software does not find the properties of bone material, the entire value of material properties will be entered manually. One of the literatures used in determining the value of these material properties is research conducted by Faizal in 2018 [11] with the following description:

Table 1. Human bone material properties

Material properties	Bone	Drill bit
Young's modulus (GPa)	17	193
Poisson's ratio	0.4	0.3
Heat expansion coefficient (mm °C $^{-1}$)	27.5 x 10 $^{-6}$	1.206 x 10 $^{-5}$
Thermal conductivity (W m $^{-1}$ K $^{-1}$)	0.38	17
Specific heat (J kg $^{-1}$ K $^{-1}$)	1260	500
Emissivity	0.97	0.7

The stress flow model equation will represent the properties of the bone material to be made. The form of the model can be described in the form of equations as follows:

$$\sigma\ (\varepsilon_p, \dot{\varepsilon_p}, T) = c. \varepsilon_p^n . \dot{\varepsilon}_p^m . \left(\frac{T}{T_0}\right)^{-r} + y \quad (1)$$

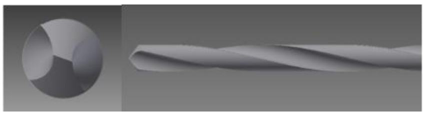
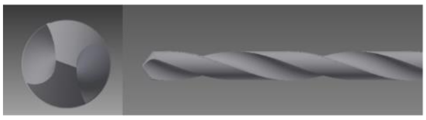
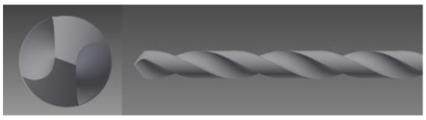
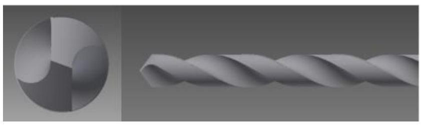
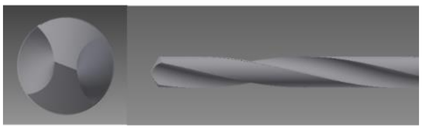
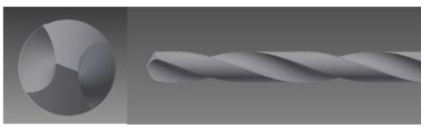
Where ε_p is the plastic strain value, $\dot{\varepsilon}_p$ is the plastic strain rate, T is the temperature, T_0 is the room temperature. In addition, the values of *c, n, m, r* and *y* are coefficient values, whose values will be determined based on the determination of the curve in the DEFORM-3D device. After the overall design concept has been determined, the next step is to determine the drilling parameters where several values will be determined as follows:

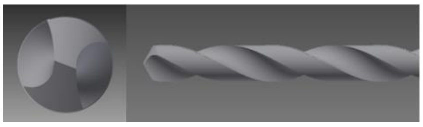
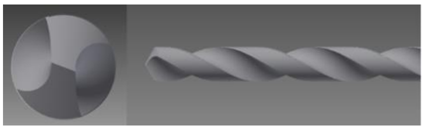
Table 2. Drilling parameters

Parameter	Nilai
Rotational speed (RPM)	1500
Feed rate (mm/rev)	0.12
Friction factor	0.3
Tool temperature (°C)	30
Drill diameter (mm)	3.5
Drill material	AISI 316
Drill mesh	*Size ratio*: 4, *min elemen size*: 0,4 mm, *elemen*: 6164, *nodes*: 1851
Work piece temperature (°C)	37
Diameter work piece (mm)	20
Thickness (mm)	5
Size mesh workpiece	*Size ratio*: 7, *min elemen size*: 0,4 mm, *elemen*: 5546, *nodes*: 1257
Drill depth (mm)	5
Drill length (mm)	110
Flute length (mm)	38

Then the overall drill design design will be made in full which is illustrated as follows:

Table 3. Embodiment design

Point angle	Helix angle	Desain
105°	13°	
	20°	
	28°	
	30°	
120°	13°	
	20°	

Point angle	Helix angle	Desain
	28°	
	30°	

After all data is considered complete, the next step is to proceed to the simulation stage. The following is an overview of the initial phase of the start of the simulation:

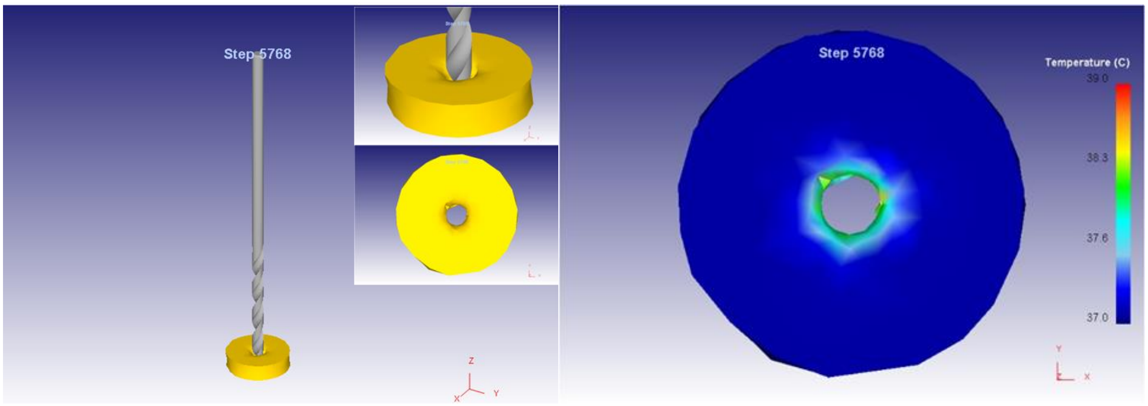


Figure 1: There is an overview of the drilling simulation that has been carried out on the bone simulation below (a) Simulation process in DEFORM-3D software (b) Simulation result with temperature change

The changing temperature of the bone model through color changes, with the indicator on the right side of the model showing blue color is an indication that the model temperature is at a low point while the red color can be interpreted as the temperature is at the highest point. Figure 1 shows a complete picture of the change in bone drilling temperature based on the change in time. The x-axis represents the drilling time while the y-axis shows the temperature change. After the entire bone drill bit model has been tested through the simulation process, the maximum temperature value of the bone model will be generated for further analysis. The test data will be taken twice in one test parameter to ensure the data taken is more accurate.

3. Results

After all the drilling simulation test data in the form of the highest temperature value for each parameter has been considered complete, it will be collected and described in tabular form as follows:

Table 4 Simulation results

No	Point angle	Helix angle	Temperatur (°C)		Average (°C)
			Data 1	Data 2	
1	105°	13°	39.018	39.012	39.018
2		20°	41.126	39.164	41.126
3		28°	41.121	38.838	41.121

No	Point angle	Helix angle	Temperatur (°C)		Average (°C)
			Data 1	Data 2	
4		30°	39.372	39.700	39.372
5	120°	13°	39.872	39.978	39.872
6		20°	39.531	39.326	39.531
7		28°	40.100	40.279	40.100
8		30°	40.490	40.305	40.490

From the graph above, it can be seen that the highest temperature increase in simulated drilling is at a parameter value of point angle of 105° with a helix angle value of 20° amounting to 41.126°C. As for the lowest average value is at 39.018 °C produced by point angle 105° and helix angle 13°. To get a clearer picture of influence of each parameter on the increase of drilling temperature then a more in-depth analysis will be conducted in-depth analysis using the full factorial method.

Table 4 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	2.06380	0.68793	35.95	0.002
Linear	2	2.06263	1.03131	53.90	0.001
Point angle	1	1.56911	1.56911	82.00	0.001
Helix angle	1	0.49352	0.49352	25.79	0.007
2-Way Interactions	1	0.00118	0.00118	0.06	0.816
Point angle*Helix Angle	1	0.0118	0.00118	0.06	0.816
Error	4	0.07654	0.01914		
Total	7	2.14034			
Model Summary		S	R-sq	R-sq(adj)	R-sq(pred)
		0.138330	96.42%	93.74%	85.70%

Based on the results of the full factorial analysis, the value of R-sq value of 96.42% indicates that the geometry parameter contributes by 96% of the temperature change.

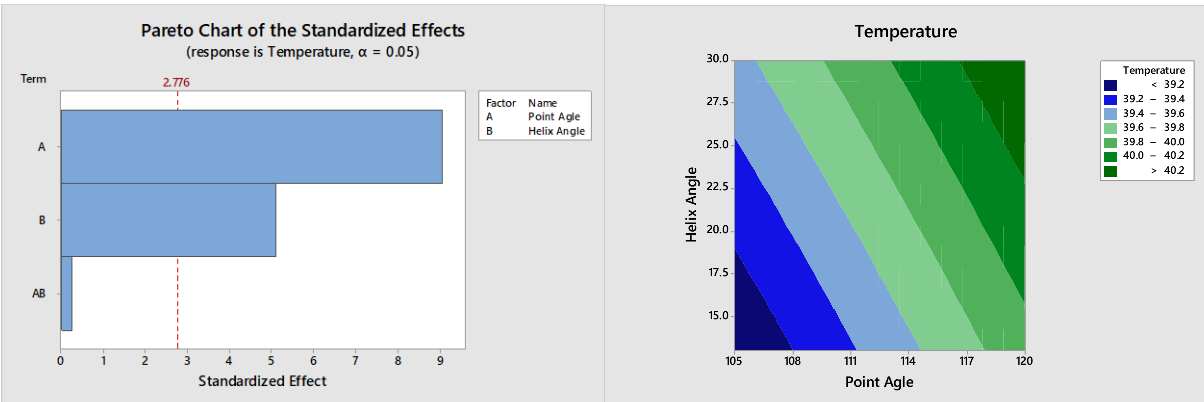


Figure 2: There is an overview (a) Pareto chat (b) Contour plot

On the Pareto diagram, it can be seen that the value of A which represents the point angle and B which represents the helix angle has crossed the red line with a limit value of 2,776 which symbolizes the significance limit. It can be seen that the point angle and helix angle values have crossed the limit so that the two factors affect the temperature change compared to the interaction between the two, which is denoted by AB. This can be reflected in the P-value which is less than 0.05, namely the point angle of 0.001 and helix angle 0.007. Furthermore, the contour plot shows that there is a gradation of color changes that represent the temperature changes that occur based on the interaction between the point angle and helix angle values. Then from the results of factorial analysis, it can also be seen that the temperature value = 31.99 + 0.0631 Point Angle + 0.0506 Helix Angle - 0.000190 Point Angle. Based on data analysis then produced several solution concepts where of the overall solution concept above the value of helix angle with a wider angle is the main choice to get the lowest drilling temperature the lowest drilling temperature. The use of helix angle helix angle can help remove bone chips and debris more efficiently, and prevent the drill bit from jamming due to the drill bit from jamming due to chips that accumulate. explains that larger point angle values larger in certain combinations can reduce the value of force and torque in drilling therefore, under these conditions the selection of a larger angle can make it possible to lower drilling temperature

4. Discussion

For further development, it can be done by adding geometry values to the tool not limited to the helix angle and point angle values but can add other parameters, namely web thickness, drill bit diameter size or other drilling parameters.

5. Conclusions

The combination of 105° point angle and 13° helix angle parameters is the best combination because based on the simulation results, a relatively low temperature increase value is obtained. In addition, the helix angle and point angle factors are the most dominant factors in influencing the increase in bone drilling temperature during the simulation when compared to the combination between the two.

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