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# OPTIMIZATION OF ORTHOPAEDIC DRILLING: A TAGUCHI APPROACH

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**Abstract**-Bone drilling is a common procedure to prepare an implant site during orthopaedic surgery. An increase in temperature during such a procedure can result in thermal osteonecrosis which may delay healing or reduce the stability of the fixation. Therefore it is important to minimize the thermal invasion of bone during drilling. The Taguchi method has been applied to investigate the optimal combination of drill diameter, feed rate and spindle speed in dry drilling of Polymethylmethacrylate (PMMA) for minimizing the temperature produced.

**Keywords** - Bonedrilling; Orthopaedic surgery; Thermal Osteonecrosis; Taguchi method;

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## I. INTRODUCTION

Bone fracture is common in day to day life. Fracture occurs when the bone is subjected to the forces (direct blows, falls or twisting) which it is unable to sustain. Fractured bones are capable of healing itself naturally by generating new bone forming cells and blood vessels at the fracture site. Therefore restoring of the fractured parts to their initial position and maintaining them there until the bone heals is crucial. Drilling of bone is a common procedure to produce hole for screw insertion to fixate the fracture devices and implants for immobilization. Orthopaedic drilling during surgical process causes increase in the bone temperature which can result in the permanent or temporary loss of blood supply to the bones. In the absence of blood supply, the bone tissue dies and causes the bone to collapse, termed as thermal osteonecrosis [1-3]. The compressive force acting on the fixation usually demands for the high degree of stability of the fixating screws. To ensure this stability the threads of the screw must engage or grip the bone enclosing the drilled hole. But necrosis causes breakdown of bone around the implantation site leading to the loosening of fixation [4]. Thus the method of internal fixation of fractured parts for faster recovery is advantageous only if the thermal necrosis of the bone can be avoided. Hence, drilling of bone with minimum temperature is a major challenge for orthopaedic fracture treatment. In this study, effects of drill diameter, feed rate and spindle speed on temperature generated in the dry drilling of PMMA were investigated using the Taguchi experimental design method. An orthogonal array and the signal-to-noise(S/N) ratio were employed to analyze the effect of the process parameters [5].

## II. TAGUCHI APPROACH

Taguchi method is a powerful technique for the design of experiments [6]. It is very effective to deal with the responses influenced by multi variables. The

main process control Parameters are examined in this method to optimize the designs for performance, quality and cost. The traditional experimental design methods are tangled and difficult to use. In comparison to it, the Taguchi method provides a significant reduction in the number of experiments to be performed for the same number of process control factors [7].

Orthogonal arrays (OAs) and the Signal to Noise ratio(S/N) are the two important tools used by the Taguchi method. OAs greatly reduces the number of experiments by considering, for each level of any one factor, all the levels of other factors occur at an equal number of times thereby giving a balanced design. OAs allows the researcher or designer to study many process control factors simultaneously and can be used to evaluate the effect of each factor independent of the other factors [7]. Hence, the advantages offered by OAs can be concluded as: to save effort in conducting experiments, to save experimental time, to save cost and to find out the significant factors fast.

Signal to Noise ratio is a quality indicator that indicates the scattering around a target value. Signal represents the effect on the average response while the noise is a measure of the influence on the deviation from the average response [7]. A high S/N ratio is desirable as the signal level is much higher than the random noise level, so represents the best performance [6-8]. The procedure and steps of the Taguchi design are shown in "Fig. 1".

### A. Selection of Quality Characteristics

Three types of quality characteristic are used in the Taguchi methodology: lower is better, nominal is better and higher is better. As the temperature generated should be minimum during the surgical drilling therefore lower is better (LB) quality characteristic was selected to obtain the optimal

combination of process control parameters [9]. The LB quality characteristic S/N ratio of each trial is expressed as

$$\frac{S}{N} = -10 \log\left(\frac{1}{m} \sum_{i=1}^m Y_i^2\right) \quad (1)$$

Where Y is the experimental value in the  $i$ th test and  $m$  is the number of repeated test.

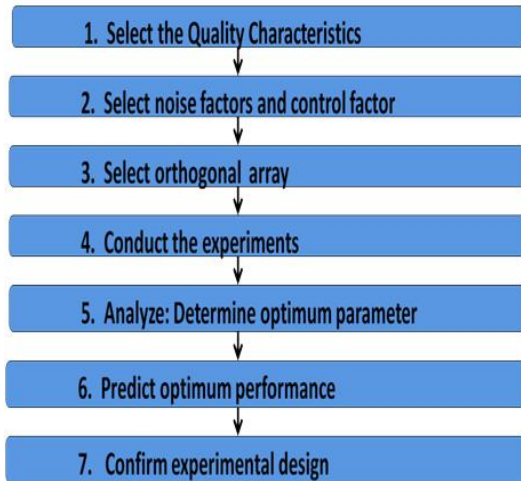


Fig. 1. Steps in Taguchi design of experiments[7]

### B. Selection of Parameters

In Taguchi design of experiments the process parameters are divided into two groups: control factors and noise factors. The control factors are the controllable parameters which affect the process significantly whereas noise factors are the special variables that affect the process and are either uncontrollable or too expensive to control [10]. In this study, the drill diameter, feed rate and spindle speed are considered as the control factors as these parameters can significantly affect the temperature generated during drilling. The control factors along with the levels used are given in the table I.

Table I : Factors and Levels Considered For Drilling

	Control Factor	Level 1	Level 2	Level 3
A	Drill Diameter(mm)	6	8	10
B	Feed Rate(mm/min)	35	40	45
C	Spindle Speed (rpm)	1500	2000	2500

### C. Selection of Orthogonal array

The orthogonal array is utilized for determining the combination of various levels of different control factors for which the experiments are to be carried out. The optimal combination of the levels of control factors for the process is determined by analyzing the data acquired using OA. Taguchi's OA is selected on the condition that the total degrees of freedom (DOF) of the OA must be greater than or equal to the total

DOF required for the experiment [11]. DOF is defined as the number of comparisons needed to determine which level is better. For each control factor the DOF is one less than the total number of levels (DOF of a factor = Total no of levels of factor - 1). The DOF for three control factors, each at three levels is  $6(3 \times (3 - 1))$ . Therefore a  $L_9$  OA was selected for this study which is shown in the table II.

Table II : Experimental Design Using  $L_9$  Oa

Trial	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

### D. Experimental Work Materials

The work material used is a Polymethylmethacrylate (PMMA). Human bones are not easily available also it varies widely in density, cortical thickness and other parameters of interest. A more uniform and consistent material was desirable having properties similar to bone, allowing the results to be extrapolated for real surgical processes. PMMA has the properties comparable to the bone and is an acceptable surrogate for bone in such studies [12]. The properties of bone and PMMA are shown in the table III [12].

Table III : Comparison of Properties For Bone And Pmma

PROPERTIES	BONE	PMMA
Thermal conductivity (W/mK)	0.1-0.35	0.15-0.4
Specific heat (J/KgK)	1300	1400
Thermal diffusivity(m <sup>2</sup> /Sec)	$0.3 \times 10^{-6}$	$0.11 \times 10^{-6}$
Density(Kg/m <sup>3</sup> )	1800	1400

Specimens were made by using PMMA block of size 12cm x 7.5cm x 2cm. A hole of 1mm diameter is made at a depth of 5 mm to accommodate a thermocouple 0.7mm from the edge of test drill hole (shown in “Fig. 2”).

*Machine*

The experiments were conducted using the 3 axis MTAB Flexmill. An Omega K- type thermocouple was used for temperature sensing. NI-DAQ 9219 was used with LABVIEW Software for the acquisition of the data. The experimental set up is shown in the “Fig. 2”.

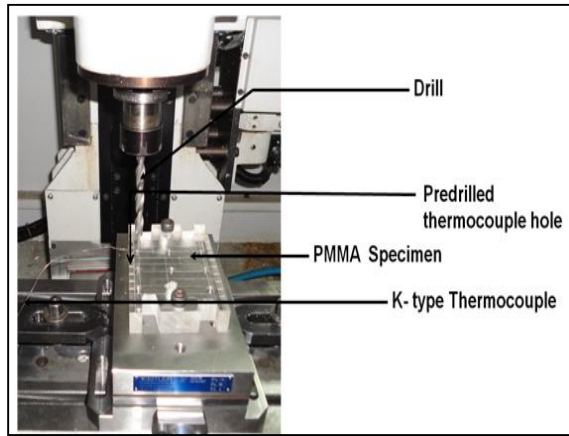


Fig. 2. Experimental set up

**E. Analysis of the Experimental Response**

The maximum value of temperature obtained for each trial is used for the analysis. This criteria was used to avoid any possibility of thermal osteonecrosis (ON). All the values of bone temperature, not their mean values must be below the cut-off point for ON [13].

S/N ratio for each response is calculated by using (1) shown in the table IV .The average of all the factors at each level is then calculated from the obtained S/N ratio shown in the table V.

Table Iv : Temperature Obtained And S/N Ratio Of Each Trial

Trial	Temperature(°C)	S/N[dB]
1	41.8430	-32.4325
2	45.8415	-33.2252
3	53.9381	-34.6379
4	51.7947	-34.2857
5	50.6979	-34.0998
6	46.7106	-33.3883
7	59.5590	-35.4989
8	52.5298	-34.4081
9	54.0100	-34.6495

Table V : Average S/N Ratio Of All Factors At Each Level

Level	Drill Diameter	Feed Rate	Spindle Speed
1	-33.43	-34.07	-33.41
2	-33.92	-33.91	-34.05
3	-34.85	-34.23	-34.75
Delta	1.42	0.31	1.34
Rank	1	2	3

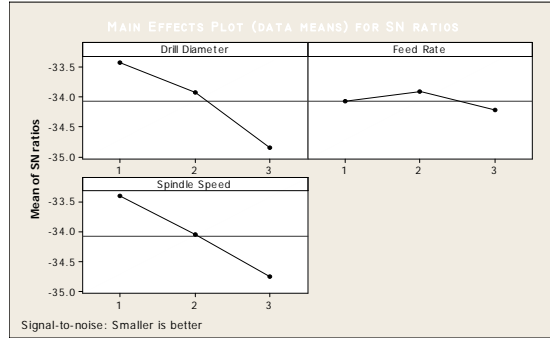


Fig. 3. Main Effects Plot For S/N ratio(mean)

**F. Prediction of Optimum Performance**

Table V summarizes the significance of each factor on the PMMA drilling process. It is found that the diameter has the highest influence on temperature produced during drilling PMMA, followed by the spindle speed and feed rate respectively. The optimum combination of the parameters for minimum temperature generation is A1B2C1 (shown in “Fig. 3”)

**G. Confirmation Experiments**

The reason for conducting the confirmation experiments is to validate the conclusions obtained during the analysis phase. An Experiment for three factors and three levels investigates 27 conditions. In the present study using L<sub>9</sub> OA only nine conditions are investigated. Therefore, investigating the unlisted conditions in the L<sub>9</sub> OA is especially important. The confirmation test involves conducting the experiments with the combination of the parameters unlisted in L<sub>9</sub> OA and then comparing it with the optimal condition. Table VI summarizes the confirmation tests.

Table VI : Confirmation Tests

Characteristics	Conventional Design 1	Conventional Design 2	Conventional Design3	Optimal Design
	A1B1C2	A1B2C3	A1B3C2	A1B2C1
Experimental Value	47.6506	52.440	52.7445	46.0504
S/N ratio	-33.5614	-34.4105	-34.4436	33.2647

The Gain [dB] estimated by subtracting the S/N ratio of conventional design from optimal design is shown in the table VII.

Table VII : Gain Calculation

Conventional	Optimal	Gain [dB]
Design S/N ratio	Design S/N ratio	
A1B1C2 33.5614	A1B2C1 33.2647	0.2967
A1B2C3 34.4105	A1B2C1 33.2647	1.1458
A1B3C2 34.4436	A1B2C1 33.2647	1.1789

### III. CONCLUSION

From this study, the following conclusions are made:

- I. Diameter has the highest influence on temperature produced during drilling PMMA, followed by the spindle speed and feed rate respectively.
- II. The optimal combination of the control factors is A1B2C1 for minimum temperature generation.
- III. The optimal combination is also validated by performing the confirmation experiments. For each comparison of optimal combination with the conventional, a positive gain is obtained.

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