LUPINE PUBLISHERS

Current Trends on Biotechnology & Microbiology

DOI: 10.32474/CTBM.2019.01.000117

ISSN: 2641-6875

Short Communication

Investigation and Optimization of Temperature and Force Behavior in High-Speed Bone Drilling

Mohsen Sarparast* and Tohid Jahangirpoor

Department of Mechanical Engineering, Iran

***Corresponding author:** Mohsen Sarparast, Department of Mechanical Engineering, K.N. Toosi University of Technology, Tehran, Iran

Received: December 02, 2019 **Published:** December 05, 2019

Abstract

Nowadays, Implantation is one of the inevitable methods of internal fixation in orthopedic surgery and dentistry. In many cases, bone drilling causes an increase in bone temperature (more than 47 °C) and this phenomenon leads to thermal osteonecrosis. In addition, excessive thrust force during drilling process increases probability of drill bit fracture. In this study, it has been shown that high-speed bone drilling is an appropriate method for descending process temperature and force simultaneously. Also, rotational speed, feed rate and tool diameter are the most important factors of the process. In high-speed bone drilling, contrary to conventional drilling process, high rotational speed results in a decrease in process temperature and force. Therefore, in robotic surgery high-speed bone drilling is considerably suitable method for implantation

Keywords: Orthopedic surgery; high-speed bone drilling; design of experiments; force; temperature; thermal osteonecrosis

Introduction

Implantation is one of the prominent processes in medical surgery. Most of the operations in orthopedic surgery and dentistry need drilling for fixation of implant in the bone. Therefore, during drilling process owing to low thermal conductivity of bone tissue (approximately 0.38-2.3J/mK), the temperature in drilling zone increases significantly (higher than 47 °C) [1]. This phenomenon leads to cell death which is called thermal osteonecrosis. In fact, this decreases in material stiffness, causes the fitting screws to wobble in the bone and increases the period of treatment [2,3]. In addition, large amount of thrust force during conventional bone drilling increases the probability of drill bit fracture. Therefore, reducing drilling temperature and force is a critical objective and has significant role in robotic surgery.

Materials and methods

Statistical analysis

In this study, in order to determine the number of experiments and considering the interactions between process parameters, response surface method was used. By using this method, the number of tests needed to reach a high accuracy response was determined [4]. The general form of the equation which includes the main effect of the factors and effective interactions is presented in equation (1) [5].

$$y = \beta_0 + \sum_{i=1}^{K} \beta_i x_i + \sum_{i=1}^{K} \beta_{ii} x_i^2 + \sum_{i} \sum_{j} \beta_{ij} x_i x_j + \varepsilon \quad (1)$$

Where

β is the regression coefficient matrix,

x_i is the experiment input factor,

x_i^2 square of experiment input factor,

$x_i x_j$ are the second -order interactions of the input

Experimental setup

Since bovine cortical bone's physical and mechanical properties are very similar to human bones [6,7], a piece of fresh bovine bone was used for experiments. A high-speed conduction motor (model Arel TIP: ARFM 1Y-M3 with a maximum of 18000RPM), K-type thermocouple, load cell (model Zemic L6E3 with the capacity of 500N and resolution of 0.01) and HSS drill bits were also used in order to conduct experiments [8] (Figure 1).

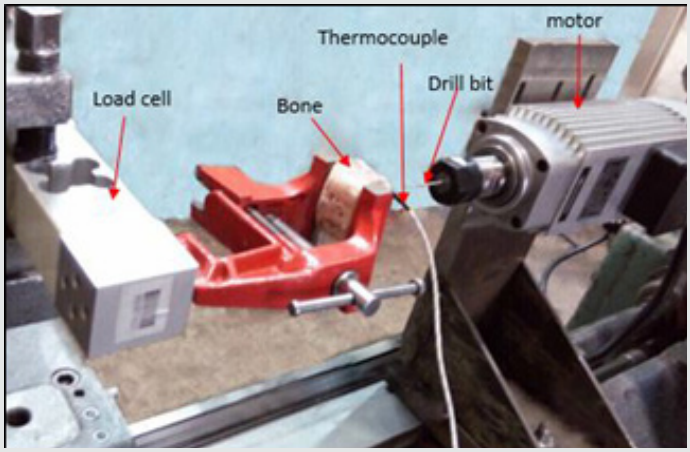

Figure 1: The experiment set up and thermocouple position [8].

Results and Discussion

In high-speed bone drilling process, high rotational velocity contributor to growing the friction between the drill bit and the hole wall and it result is rising bone temperature. In addition, in this process, there is an inverse relationship between the tool feed rate and bone temperature (bone temperature has an insignificant fall with increasing feed rate). As a result, there is no limitations when using high feed rates. Using low diameter drill bit decreases the friction in drilling zone which causes bone temperature to fall and reduces risk of thermal necrosis. Since in this process the chip is in powder form and the existence speed is high, in high-speed bone drilling the drill force is considerably lower than that of ordinary drilling process.

Conclusion

There is an optimum point in process parameters when the rotational speed, feed rate and tool diameter are 11778rpm, 50mm/min and 2mm, respectively. In this case the values of temperature and force are 33.4 °C and 15.85N. Therefore, according to low thermal damage and thrust force, high-speed bone drilling is preferred to conventional drilling. Also, findings in this research can help surgeons to select proper set up parameters in order to reduce process temperature and force.

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DOI: 10.32474/CTBM.2019.01.000117