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Research Paper

Optimization of process parameters for drilled hole quality characteristics during cortical bone drilling using Taguchi method

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ABSTRACT

Orthopaedic surgery involves drilling of bones to get them fixed at their original position. The drilling process used in orthopaedic surgery is most likely to the mechanical drilling process and there is all likelihood that it may harm the already damaged bone, the surrounding bone tissue and nerves, and the peril is not limited at that. It is very much feared that the recovery of that part may be impeded so that it may not be able to sustain life long. To achieve sustainable orthopaedic surgery, a surgeon must try to control the drilling damage at the time of bone drilling. The area around the holes decides the life of bone joint and so, the contiguous area of drilled hole must be intact and retain its properties even after drilling. This study mainly focuses on optimization of drilling parameters like rotational speed, feed rate and the type of tool at three levels each used by Taguchi optimization for surface roughness and material removal rate. The confirmation experiments were also carried out and results found with the confidence interval. Scanning electrode microscopy (SEM) images assisted in getting the micro level information of bone damage.

1. Introduction

Drilling through the bone is a necessary action when a major fracture is treated by the direct method of bone fracture treatment (Udiljak et al., 2007; Pandey and Panda, 2013a, 2013b). Drilling is a mechanical process in which a drill bit revolving on its own axis that is called the drilling axis creates a cylindrical cavity in the material by applying axial load on the rotating drill. This mechanical action between the drill and that material affects the surface properties in different aspects. This type of bone fracture treatment is known as the direct method as in this method, evidently, direct fixation of bone takes place with the help of screws and implants (Udiljak et al., 2007; Pandey and Panda, 2013a, 2013b). Treatment of bone fracture is quite a technical assignment which must be handled in a very skillful way so that the joint must last long. Bone joints may simply fail if proper precaution is not taken during bone drilling. Some problems get initiated during drilling or machining are caused due to mechanical damage to the surroundings of the bone in the form of micro-cracks, drill-vander and irregular surface topography of drilled walls. This damage

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may lead to failure of the joint when the affected person engages with his daily work. A pullout of the screw can take place because the surface damage leads to low anchorage strength in the bone and the screw. Previously most of the research focused on bioactive coats and surface texturing to improve the pullout strength of bone screw joint (D'Lima et al., 1998; Feighan et al., 1995; Dean et al., 1995; Hasegawa et al., 2005; Gefen, 2002; Lin et al., 2011; Tsai et al., 2009). Engh et al. (1995) revealed that 35% of the histological fields confirmed some bone in-growth, and overall 24% of the pore area was filled with bone. Tisdel et al. (1994) reported much lower bone growth in the pores of a fiber mesh implant (in a rabbit intramedullary model): after 24 weeks, 11% of the available pores were filled with bone, which is up to 26% more than the implant with hydroxyapatite coated and having maximal interface strengths reaching 3.7 MPa. Turner et al. (1986) reported a mean-linear bone regeneration of 39% and mean bone in growth of 23% in case of beaded and 37% in case of fiber mesh of the pore volume, but Jasty et al. (1989) reported 22% mean area density of bone within the available pore space for femoral components at 6 weeks. Different authors worked on cortical bone drilling with different variable parameters (Udiljak et al., 2007; Pandey and Panda, 2013a, 2013b, 2014, 2015; Hillery and Shuaib, 1999; Alama et al., 2011; Reingewirtz et al., 1997). Some researchers also reported work on surface roughness of cortical bone drilling with different sets of bone drilling parameters and optimized the best set of parameters using different optimization techniques (Pandey and Panda, 2013a, 2013b, 2014, 2015). Alam et al. (2009) observed the surface roughness of cortical bone drilled specimen. The bone specimen was drilled with conventional and vibrational drilling technique and surface roughness was compared. From the results it is concluded that hole surface roughness with conventional method is more than the vibrational method in the range of 6.5% to 11%. Singh et al. (2015) compared ultrasonic and conventional cortical bone drilling technique for the surface topography of bone drilled specimens. From the results it is observed that ultrasonic drilling provides better surface finish and less damage to the bone surrounding the drill point. In these studies, the main focus is to improve the surface properties of bone surroundings during cortical bone drilling. During orthopaedic surgery, not only the surface but the drill time is also a major factor that needs to be focused on so that surgery take less time with better accuracy and less damage to the bone periphery. In the present study, these two responses of cortical bone drilling are studied with different sets of parameters. Taguchi optimization technique helps to get these best set of drilling parameters for better results.

Table 1 – Comparison for the properties of bovine bone and human bone (Pandey and Panda, 2013a, 2013b, 2014, 2015; Alam et al., 2009).

Bone property	Bone type	
	Bovine	Human
Tensile strength (MPa)	140–250	130–200
Compressive strength (MPa)	45–150	40–145
Young's modulus (GPa)	10–22	10–17
Shear modulus (MPa)	3	3
Density (Kg/m^3)	1950–2100	1800–2000
Poisson's ratio	0.33	0.4
Specific heat (J/KgK)	1300	1330
Thermal conductivity (W/mK)	0.1–0.3	0.1–0.43

2. Material and methodology

2.1. *Cortical Bovine Bone*

Experimentation was carried on cortical bovine bone (Pandey and Panda, 2013a, 2013b, 2014, 2015; Alam et al., 2009; Singh et al., 2015). The bovine bone has the resemblance to the human bone in the terms of mechanical properties (Pandey and Panda, 2014; Singh et al., 2015) as shown in Table 1. It is easily available from local slaughter houses. To maintain the properties, fresh bovine was purchased from the slaughter house and it was made sure that the bone was taken from the animal that had been slaughtered on that particular day. No animal was harmed specifically for the experimentation purpose. The bovine bone used for experimentation is shown in Fig. 1.

The study was carried out on the cortical part of the bone. Thus the epiphysis part of the bone was cut from both the ends and inner bone marrow was squeezed out. Two holes of diameter 8 mm were to be drilled at the extreme ends of the specimen so that it could be held easily over the drilling

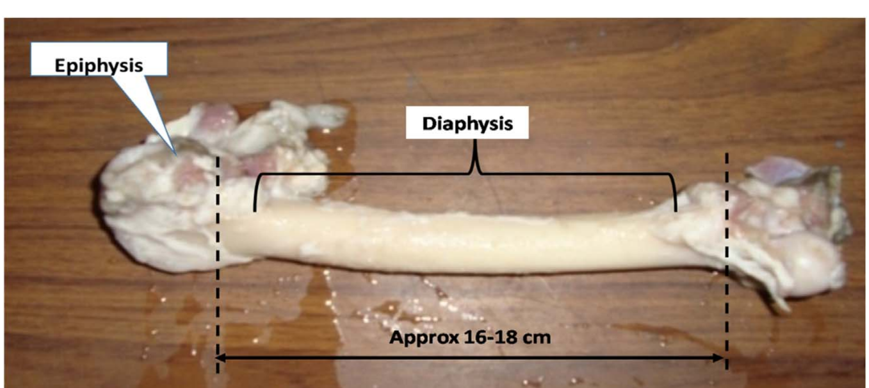

Fig. 1 – Bovine cortical bone used for experimentation.