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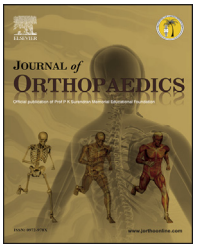

Original Article

Optimization of multiple quality characteristics in bone drilling using grey relational analysis

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ABSTRACT

Purpose: Drilling of bone is common during bone fracture treatment to fix the fractured parts with screws wires or plates. Minimally invasive drilling of the bone has a great demand as it helps in better fixation and quick healing of the broken bones. The purpose of the present investigation is to determine the optimum cutting condition for the minimization of the temperature, force and surface roughness simultaneously during bone drilling.

Method: In this study, drilling experiments have been performed on bovine bone with different conditions of feed rate and drill rotational speed using full factorial design. Optimal level of the drilling parameters is determined by the grey relational grade (GRG) obtained from the GRA as the performance index of multiple quality characteristics. The effect of each drilling parameter on GRG is determined using analysis of variance (ANOVA) and the results obtained are validated by confirmation experiment.

Results: Grey relational analysis showed that the investigation with feed rate of 40 mm/min and spindle speed of 500 rpm has the highest grey relational grade and is recommended setting for minimum temperature, force and surface roughness simultaneously during bone drilling. Feed rate has the highest contribution (59.49%) on the multiple performance characteristics followed by the spindle speed (37.69%) as obtained from ANOVA analysis.

Conclusions: The use of grey relational analysis will simplify the complex process of optimization of the multi response characteristics in bone drilling by converting them into a single grey relational grade. The use of the above suggested methodology can greatly minimize the bone tissue injury during drilling.

1. Introduction

Drilling of bone is common to produce hole for screw insertion to fix the fractured parts in wide range of orthopaedic surgeries. Bone drilling temperature and forces plays a very important role on the outcome of orthopaedic operation because a higher dose of them produces high heat effected zone and micro cracks in the bone resulting in damage or even

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death of the bone cells (osteonecrosis) surrounding the drilled hole. This damage or death of bone cells may delay the process of healing or reduce the stability and strength of the fixation.[1–5] Moreover, the improper surface finish hampers the proper engagement of the screws with the bone surrounding the drill site and can lead to the loosening of fixation.[5] In past, many researchers have studied the process of bone drilling to evaluate the effect of spindle speed and feed rate on temperature force and surface roughness. Thompson[6] reported that the temperature increases at 2.5 mm and 5.0 mm from the drill hole with increasing speed from 125 rpm to 2000 rpm. Vaughan and Peyton[7] suggested that increasing the spindle speed from 1000 rpm to 10000 rpm increases the bone drilling temperature. Matthews and Hirsch[8] investigated the bone drilling process on human femora and observed no significant changes in drilling temperature on increasing the spindle speed from 345 rpm to 2900 rpm. Brisman[9] performed drilling experiments on bovine cortical bone with drilling speeds of 1800 and 2400 and reported that the drilling temperature increases with the increase in the drilling speed. Hillery and Shuaib[10] conducted drilling investigations on human and bovine bone and found that the temperature decreases significantly with increasing drill speed from 400 rpm to 2000 rpm. Nam et al[11] conducted bone drilling experiments on bovine ribs with 600 rpm and 1200 rpm and suggested that the temperature increases with increasing the drilling speed. Sharawy et al[12] drilled pig jaw bones with three spindle speed of 1225 rpm, 1667 rpm, and 2500 rpm and showed that the temperature decreases with increase in spindle speed. Lee et al[3] performed drilling experiments on bovine bone in the ranges of 800 rpm–3800 rpm and concluded that the bone drilling temperature rises with increase in drill speed. The effect of increase in feed rate on temperature is reported by Augustin et al[13] and Lee et al,[3] they found that the temperature decreases with increase in feed rate as the increase in feed rate increases the rate of heat generation rate but causes reduction in drilling time therefore less total heat is generated. The review of the effect of spindle speed on bone drilling temperature suggests no consistent trend. Some suggests low spindle speed as they found that the temperature increases with increase in spindle speed while others suggest a decrease in temperature with increase in spindle speed.

Jacob et al[14] investigated the drilling of bovine tibia with several drill bits under different conditions of feed rate and rotational speed to study the behaviour of thrust force. They found that the thrust force increases on increasing the feed rate and decreases with the increase in spindle speed. Wiggins and Malkin[15] used common surgical twist bit, general purpose twist bits and specially constructed spade bit to study the variation of the thrust force with feed rate. They reported that with all types of drill bits the increase in feed rate causes increase in thrust force. Udiljak et al[16] performed bone drilling investigations with various cutting speed and feed rate and observed the similar phenomenon as reported by Jacob et al Ueda et al[17] used Taguchi method to optimize the drill bit specifications for minimum force generation during drilling of porcine femur without optimizing the drilling parameters. Similar results were observed by Lee et al[18] using their theoretically developed mechanistic model and experimental investigation on bovine bone for predicting thrust force in

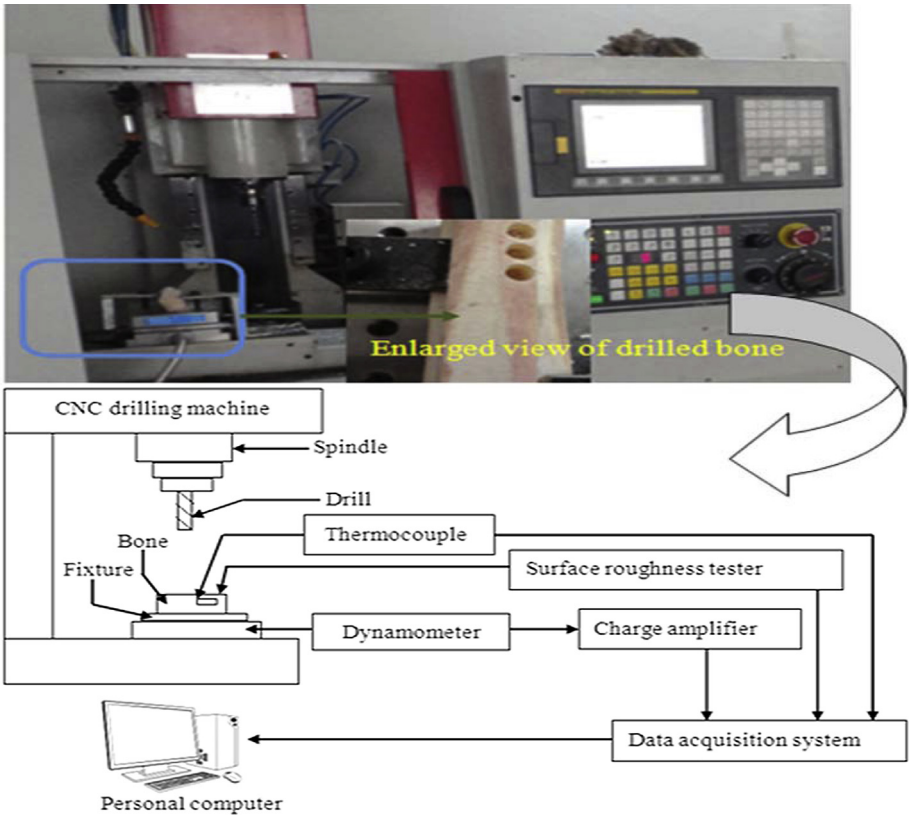

Fig. 1 – Experimental set up.