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DRILLING IN BONE: LIMITATIONS AND DAMAGE CONTROL BY DRILL SPECIFICATIONS AND PARAMETERS

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Abstract

Drilling in bone is an inevitable operation performed to join damaged bone during accidents. Drilling facilitates use of screws and plates and in this immobilisation of bone is achieved which is a primary requirement for natural bone growth and re-joining. To study bone drilling, threshold temperature [VI] has to be the prime concern and accordingly drilling parameters and specifications are to be selected otherwise irreversible[III] bone damage can occur. In this study, drilling process is conducted on a sheep bone and optimization of drilling parameters is suggested using Taguchi and ANOVA method, so that the cell damage can be on lower side. To control thermal necrosis an intelligent drilling machine is also proposed.

Keywords: Bone drilling, threshold temperature, optimization

I. Introduction

Bone drilling is performed frequently for fixations insertion. In case of accidents and trauma situations the numbers of drills require may be multiples. The bone drilling is a precision work both from mechanical aspect as it involves handling of drilling machine with controlling of spindle speed, manual feed rate, depth of cut, drill tool geometry and chip flow rate. From medical aspect the bone cell thermal damage (thermal necrosis) [XII], patient early rehabilitation and post-operative morbidity are prime considerations and so this precision task requires knowledge, skill and experience of surgeons. In previous research work it is clear that if the temperature at drilling location reaches more than 47^0c and remains the same for 30 seconds, it could damage the cells permanently and so this is mentioned as threshold temperature. During interactive sessions with medical practitioners, currently a number of drilling techniques like are adopted, so that heat generation can be controlled.

Bone skeleton structure forms the supporting frame of a living animal body, bones take the substantial load during body movement, lifting weights and running. Bones are calcified connective tissue, comprising of minerals, collagenous protein, lipids and water. The bone is physiologically active and reactive tissue and explained chemically as Ca10(PO4)6(OH)2.The bone has the following mechanical properties ;longitudinal tensile stresses (135 Mpa)

and longitudinal compression stresses (205 Mpa) and transverse tensile stresses (53 Mpa) and transverse compression stresses (131 Mpa) and shear stresses (65 Mpa) [XXII].

The causes of heat accumulation while bone drilling can be explained as; shear deformation across shear region, rubbing in between the drill bit rake face, chip, friction among the toolflank face and recently formed work piecewall's[I]. Though microvasculature and blood flow, use of saline as coolant can control the temperature rise and about 60% heat is relieved by bone chips. Due to similarity of chip shear failure both in drilling and machining, orthogonal cuttingmodel can be referred in design of heat accumulationwhile penetration. To explore the consequence of temperature on thermal damage, a precise understanding of drilling temperature is required.

In this research work, experimentation part includes drilling operation in sheep bone and then optimization of drilling specifications as drill tool diameter and drilling parameters as feed rate, spindle speed is calculated.

II. Drill Specification and Parameters

Drill specifications include drill tool geometrical aspect whereas drill depth, drill spindle speed, drill feed rate comprises drill parameters. The geometry of drill has a direct effect on heat generation at drilling site[XXII], [I]. The helix angle is the main design feature of drill bit as the quick spirals of bone fragments, lipids, marrow, blood, soft tissues find their way to get relieved from drilling site through flutes and is observed to affect the design of cutting edge and prominently fluted region geometry and similarly a significant effect on the heat and temperatures[XVI]. The drill-bit[7] flutes determine the compactness and chip removal rate from the cutting area [XIX]. As the debris chips take in a fraction of the heat produced, a rapid debris flow through the helical grooves will minimize not only the general quantity of heat transmitted to the bone [XVI] but also decrease the maximum temperature in the drilling process. It is observed that point angle has negligible overall effect [II],[VII], though design of chisel-edge has a deep consequence on the cutting forces. Point angle is linkedwith thrust forces and so its influence on heat generation is less as comparedto the cutting edges. Increasing the drill diameter increases the amount of heat generation, which results in higher temperatures[IV]. It is observed that, heat accumulation ratio varies linearly with the cutting speed, keeping other parameters constant. Growing the feed rate and individually the speed of spindle [XXI] also rises the generated heat. The primary thermal insult is get affected by the spindle speeds, spindle speed with higher values amplified the thermal damage and delayed the patient healing time[XVII].In some of the cases, the balancing of higher local heat generation and lower heat transfer to the surrounding bone is observed and in this way they both cancel one another, which makes heat generation self-regulating of the cutting speeds[XV]. As per the literature, increased spindle speed may decrease the temperatures and minimise thermal injury during orthopaedic drilling [V],[XIV].Though it could be believed that the combination of lesser feed rate and gentler spindle speed are constantly encourage to avoid thermal effects. Actually high thermal conductivity of drill bit (14 W/mK) [V]as compared to (0.56 W/mK) for bovine cortical bone[XIII], i.e. higher thermal conductivity of drill tool makes advantage to relieve heat by cutting edge heat conduction and particularly when external cooling is provided. The debris &chip flower moves the heat from the drill tool through the flutes, working as a conserving instrument. Regarding feed rate, it can be said that, for effective chip removal rate, feed rate should be more.

The noticeable forces are the thrust force generated because of the rotating drill bits push to the work piece and torque applied by the spindle speed to keep up the drill rotation. The thrust forces and torque increases radically with the increase of cutting speed, nevertheless the effect of cutting speed on torque is much lesser than the thrust force. The effect on torque is more with increase in feed rate at higher speed compared to lower speed [IX].

III. Materials and Method

The aim of research is, to detect the thermal insult in the course of orthopaedic drilling and to understand different drilling parameters in course of practice. For drilling sheep rib bone is selected because it is a suitable large-animal typical for biomedical research, availability, ease of supervision and housing, animal price, and receiving to society as a research animal[IX],[XI],[VIII]. In this study, sheep rib bone acquired from a local butcher. First, all the soft flesh tissues were detached along the specimen surface by a surgical too lafter that the bone specimen deep in buffer solution. A special container with the provision of heatingthe normal saline solution and a thermostat to give a precise temperature control is used. To pretend body temperature of 37^0C, the solution temperature was maintained. The average dimensions of specimen were thickness of 2.5 mm and surface area of 10mmX6mm, across which heat distribution is to be studied.

To achieve a realistic environment of surgery and to realize exactness CNC milling is employed for the drilling. The drill tool specifications include, drill tool diameter 2.5, 3.2 and 4.5 mm. Helix angle 30^0, point angle 118^0 and web thickness 0.9 mm. Feed rate values are 50.60 and 70 mm/min. and speed ranges were 1000, 1500 and 2000 rpm were selected. In this way, combination of three regulator elements, viz, spindle speed, feed rate and drill diameter, with three levels, 27 bone samples were drilled. Selection of feeds is arbitrary, as in orthopaedic surgery, while operating feed rate varies from doctors individually and even an individual surgeon there will also be dissimilarity, since the drill handled manually. For histopathology [X], paraffin method is preferred. Sheep rib bone is selected as it is available easily and the shape of rib bone is suitable for machine clamping. Proper care is taken to maintain the morphology and structure in natural condition .after making the drills the specimen kept in fixed with 10% Buffered Formalin Phosphate and checked continuously for softening and suitability for histopathology. The microscopic images of drilled samples clearly indicated that the empty lacunas and more and closer to the drilling site as compared tom filled lacunas that were less and a distant from drilling site.

Fig. 1: Performing of histology using microtome machine.

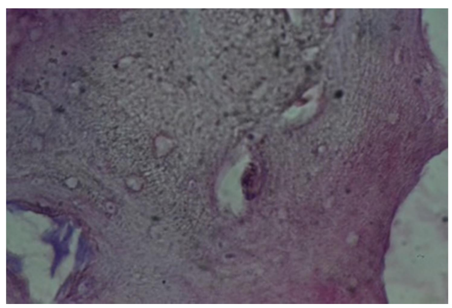

Fig. 2: Bone cells image under trinocular.

Using Minitab software Taguchi Analysis is performed. As during drilling process the lesser temperature is always preferred and so smaller the best (SB) quality characteristics is selected, to achieve optimum grouping of control factors. The considered quality characteristic is smaller the best. The equation of Signal to noise ratio is[XVIII].S/N=-10 Log $\Sigma(Yi^2/n)$

Drill bits diameter are selected considering the standard drill bit diameters frequently used by surgeons so that a results can be realistic. In Taguchi method L_{27} orthogonal arrays are used and so for 27 bone samples drilling is performed. The value of rank as in table 2, and value of contribution calculated by Anova method as in table 3, indicates the effectiveness of a particular parameter on temperature rise. In this drill diameter (rank 1, contribution 90.71%) affects temperature rise most followed by feed rate (rank 2, contribution 5.69%) and spindle speed (rank 3, contribution 2.22). Degree of freedom, (DOF) is the number of comparisons required for determining the better association of control factors. For thethree regulatingelements Taguchi's L_{27} orthogonal array explains the effect of every regulating element. The analysis of variance, Anova analysis conducted with confidence level for 95% and significance level (α) =0.05.P value< α, specifies the rejection of null hypothesis and acceptance of alternative hypothesis. The F-values for respective control factors represents the significance of that term.

Table I: Drilling control factors and levels

	CONTROL FACTOR	LEVEL 1	LEVEL 2	LEVEL 3
A	Drill Diameter (mm)	2.5	3.2	4.5
B	Feed Rate (mm/min)	50	60	70
C	Spindle Speed (rpm)	1000	1500	2000

Table II: Response values for signal to noise ratios

Level	Drill Diameter	Feed Rate	Spindle Speed
1	-32.01	-33.04	-32.82
2	-32.82	-32.78	-32.87
3	-33.62	-32.64	-32.77
Delta	1.61	0.40	0.10
Rank	1	2	3

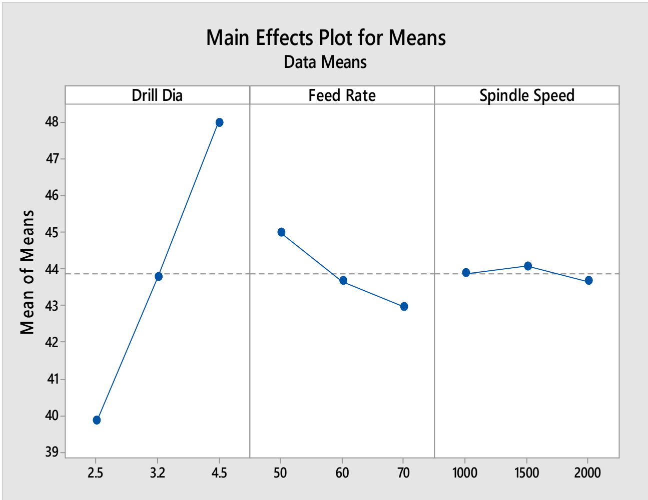

Fig.3: Graph of main effects plot for means.

Table 3: PERCENTAGE CONTRIBUTION OF CONTROL FACTORS USING ANOVA METHOD

Source	DF	Seq SS	Contri- bution (%)	Adj SS	Adj MS	F Value	P Value
Drill Diameter	2	296.85	90.71	296.85	148.42	659.93	0.00
Feed Rate	2	18.62	5.69	18.622	9.31	41.40	0.00
Spindle Speed	2	7.275	2.22	7.275	3.63	16.17	0.00
Error	20	4.498	1.37	4.498	0.22		
Total	26	327.25	100				

IV. Discussion

Bone drilling is combination of drilling parameters and specifications interaction in biological sphere. For successful conduction, this machining operation has to be conducted within a small temperature range.

Though use of coolant and chips removal is recommended for temperature control, the reach of coolant at interface of tool and bone wall is not assured as the factors like stickiness of accumulated debris in drill bit helical grooves and its layered thickness over tool surface, the length of debris (similar to chips), rate of debris breakage are affected by bone mineral density (BMD), age and gender of patient and drill speed.at the same time a special attention has to be provided for micro cracks, which may cause fatigue damages and stress fractures. For this as future prospectsa intelligent drilling machine is proposed. The suggested drilling machine with continuous temperature monitoring offers not only accurate control of heat but also time factor, otherwise temperature raise above 47^0c ,have to wait for 11 seconds. In this way before attaining temperature up to 47^0c, the corresponding signal received by infrared thermometer is send to feedback mechanism and accordingly the speed of drilling machine is reduced. The suggested drilling machine 1) avoids thermal necrosis by controlling the drilling speed, as from the two drilling parameters; speed and feed rate, only speed can be monitored and governed and feed rate is provided manually. Similarly with respect to bone dimensions drill diameter has to be selected without an alternative but here also speed variation can avoid necrosis2) reduce surgery time duration, as above attainment of47^0c, cooling waiting period is required, 3) offers hassle free surgery, 4) surgeons have not to rely on burning smell or colour change i.e. temperature related activities will be monitored by system 5) patient early rehabilitation.

V. Conclusion

Primarily drill diameter affects the heat accumulation whereas feed rate is the secondary factor and drill spindle speed is the last one. For all combinations of factors, with drill diameter of 2.5 and 3.2 mm temperature is found below 43^0c whereas for every combination with drill diameter 4.5 mm temperature is above

47^0c.From this study it is revealed that, variation and controlling of speed as compared to change in drill diameter and feed rate is can be an effective way. Another aspect is that apart from manual feed rate and drill tool diameter, drilling speed can be monitored and controlled with modifications in drilling machine.

The proposed drilling machine with speed regulation in coordination with temperature increase will be more helpful not only to orthopaedic surgeons, as the machine feedback system will guide them to avoid necrosis through speed control instead of dependency on conventional methods but also early healing and rehabilitation of patients.In future, a drilling machine is proposed, which can assist surgeons without intervening in surgery because a fully robotic machine interferes the decisions and actions at the same time it should be of less cost, easy to maintenance.

ETHICAL APPROVAL- The sheep rib bone sample is collected from a local butcher after slaughtered during and for their routine trade practice and the sheep is not slaughtered intentionally for this research work. The authors are not related directly with any live animal hence ethical approval is not required.

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