論文の内容の要旨

論文題目　Studies on Mechanics of Bone Drilling and Optimization of Drill Bit Geometry
（骨ドリル加工における加工機構およびドリル刃形状の最適化に関する研究）

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Comprehensive investigation of mechanics of bone drilling and formulation of relationship between drilling performance and drilling parameters are significant for bone drilling procedure in many fields of surgeries. Issues like drill breakage, bone breakthrough, and bone necrosis still persist for lacking the knowledge of bone drilling mechanics. Moreover, exploring new solutions to avoid these issues and to realize safe drilling of bone is still cumbersome and mainly based on experience from drilling of metals. More efficient method to develop new tools is desirable.

The main objectives of this research include investigation of mechanics of bone drilling and proposal of new tools for the procedure with a more effective method to realize safe drilling of bone. The investigation of bone drilling mechanics is mainly conducted with experiments, modeling techniques. The developed force and thermal models will enable prediction of drilling forces and temperature rise in bone for given drill point geometry, drilling process conditions, and materials used. An evolutionary algorithm - genetic algorithm, is developed to effectively optimize drill point geometry to minimize drilling forces.

A comprehensive experimental investigation of bone cutting and bone drilling is conducted in the first place. One factor at a time and orthogonal design are adopted for the orthogonal cutting of bone. Significant factors with possible interactions and regression equations are obtained by analysis of variance and regression analysis. Fundamental cutting mechanics proposed by Merchant is evaluated and an averaged error of 18% is obtained for bone material. Friction coefficient between tool rake face and bone chips is investigated and the results show that it is affected by cutting direction and rake angle, and it ranges from 0.37 to 0.53. Then design of experiment is used to investigate drilling forces and temperature rise with respect to drilling process parameters, drill bit geometry parameters, and workpiece materials. Analysis of variance is conducted to screen out significant geometry parameters and possible interactions for drilling forces and temperature rise. Response surface methodology is introduced to formulate the relationship of drilling forces and temperature rise with respect to spindle speed and feed rate. Optimized drilling conditions can be obtained from response surface equations.

The improved mechanistic force model, including an analytical description of drilling forces with respect to drill bit geometry and drilling process conditions at each section of the drill bit, is developed to predict drilling thrust force and torque. After obtaining coefficients by calibration experiments, a series of validation experiments are conducted to evaluate the accuracy of the mechanistic force model. The results show that the mechanistic model can predict the thrust force and torque accurately in a wide range of drilling conditions. The averaged prediction error is 0.73% for the thrust force, and 8.43% for the torque.

The developed thermal model, including heat generation model and two heat transfer models respectively for workpiece and drill bit, is developed to predict temperature rise and distribution in bone and drill bit. The heat generation model consists of mechanical work calculation and assumptions of conversion ratio and heat partition ratio. The governing equations of heat transfer in bone and drill bit are developed including convection effect between flute surface and chip flow or coolant. These governing equations are solved by finite difference method, and the results agree with experimental results.

The proposal of new drill bits is based on optimization of drill point geometry parameters with a genetic algorithm to minimize drilling forces. The prototypes of optimized drill bits are manufactured to verify the advantages of optimized

drill bits with experiments. The experimental results show that the drilling forces and temperature rise can be reduced greatly (more than 57%), which can be used to realize safe drilling of bone for surgeries.