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Assessment of experimental thermal, numerical, and mandibular drilling factors in implantology

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Abstract

The main factors that cause an increase in the temperature of the jaw during drilling when implanting teeth are the geometric measurements of the surgical drill, its rotational speed, and its feed rate (cutting speed). Using finite element modelling we analysed the effect of the three variables – the angle of the head of the drill bit, the rotational speed, and the feed rate – on the increase in the temperature of the bone at the point of the drill. This showed that drilling with the angle of the head of the drill bit at 70° generates a lower temperature than when it is at 90° or 118°. The same is true when the drill bit is set at 200 rotations/minute (rpm) compared with 400,800, or 1200 rpm. When the feed rate of the drill bit is 120 mm/minute it generates less heat than when it is at 90 or 60 mm/minute. An increase in temperature during drilling of the jaw has a direct relation with the rotational speed of the drill bit, and a reverse relation to its feed rate. The sharper the drill bit, the lower the temperature during drilling.

Keywords: Mandible; Drilling; FEM; Drill bit; Jaw-bone

Introduction

Various studies have tried to find out what aspects of drilling affect the bone most,[1–4] and increasing its temperature is probably the most influential factor.[5,6] Others are the structure of the bone,[7,8] whether or not the drill bit is internally cooled,[9,10] the geometry of the drill bit,[6,11,12] its rotational speed and feed rate(cutting speed),[9,12–16] the depth of drilling,[17] and the material of the drill bit.[18]

If the temperature exceeds the specified temperature during drilling it could lead to osteonecrosis, which means that the implant will not fix into the bone.[5] The critical temperature at which osteonecrosis can occur is 47 °C.[6]

Records indicate that whatever leads to an increase in the temperature of bone during drilling it is the dense portions and the bone marrow that are affected because of the gelatinous structure.[7] The density of the bone also contributes to increases in temperature.[8]

Drilling cortical bone without using internally cooled drill bits at a low rotational speed would not cause excessive heat,[9] and designing surgical drill bits with the ability to be cooled internally has been studied. These studies have shown that using these drill bits prevents the bone temperature from exceeding 47 °C.[10]

There have been many studies on the geometry of the drill bit and its effect on the generation of heat while drilling bone. Among these, three designs of drill bits that seem to increase temperature during drilling are of concern.[11] The effect of the angle of the drill bit on the temperature in bone depends

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Table 1
Thermal and physical properties of cortical bone.

Properties	Value	Source reference
Density (g/cm^3)	2.1	Huiskes R[19]
Heat capacity (J/g °C)	1.26	Huiskes R[19]
Thermal conductivity (W/m °C)	0.38	Huiskes R[19]
Heat expansion coefficient (mm/°C)	27.5×10^{-6}	Ranu HS[20]

on the feed rate of the drill bit and its rotational speed, and any change in these two variables can change the results.[12] The sharpness of the drill bit is a major factor in the increase in temperature, and if excessive force is applied to the drill bit the point of friction on the bone is directly affected, which increases the temperature in the bone beyond that permitted and leads to irreversible damage to the bony tissue.[6]

Rotational speed and feed rate also affect the increase in the temperature of bone.[12–14] The rotational speed does not affect the axial force exerted on the drill bit, but does affect the maximum heat produced in the bone during drilling, while the feed rate is directly related to the axial force exerted on the drill bit and has a reverse effect on bony temperature.[15] The rotational speed of the drill affects the increase in the temperature of the bone, but within a range of speeds at initial drilling times does not lead to osteonecrosis.[16] More accurate information about the drilling is provided for the operator at low rotational speeds, which allows him to make the desired corrections to the movement of the drill during drilling.[9]

The depth of drilling is another factor in the increase in temperature in bone, and there is a direct relation between the depth of drilling and the increase in temperature.[17]

Finally, studies have shown that diamond drill bits cause less harm to the bone than other types.[18]

Material and methods

A 3-dimensional model of the mandible was designed to be fed into DEFORM-3D software (version 6.1, Scientific Forming Technologies Corporation, Columbus, Ohio). We used 140 computed tomographic high resolution images to produce a model through MIMICS 10.01 software (Materialize NV, Leuven, Belgium). To prepare a proper point on the modelled jaw for drilling, one tooth is removed from the end of mandible through CATIA V5 CAD CAM CAE software (Dassault Systèmes, Vélizy-Villacoublay, France).

The physical and thermal properties of human cortical bone are shown in Table 1.[19,20] To assign the proper material in relation to the cortical section of the jaw the physical and thermal data shown in Table 1 are fed into the software.

The format applied for introducing flow stress into the cortical bone of the modelled jaw in calculating the mechanical properties as equation 1 in the software is defined as:

$$\bar{\sigma} = \bar{\sigma}(\bar{\varepsilon}, \dot{\bar{\varepsilon}}, \mathbf{T})$$

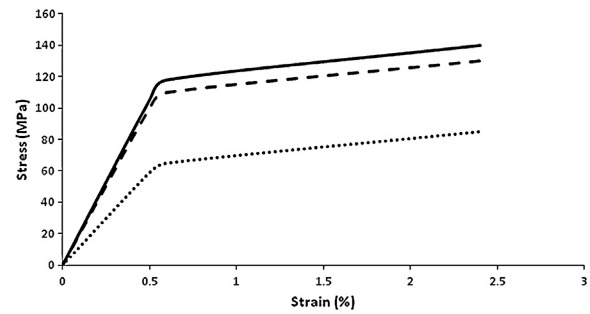

Fig. 1. True stress-strain diagram of cortical bone in three strata: solid line = 1/S, dashed line = 0.002/S, and dotted line = 0.00001/S.

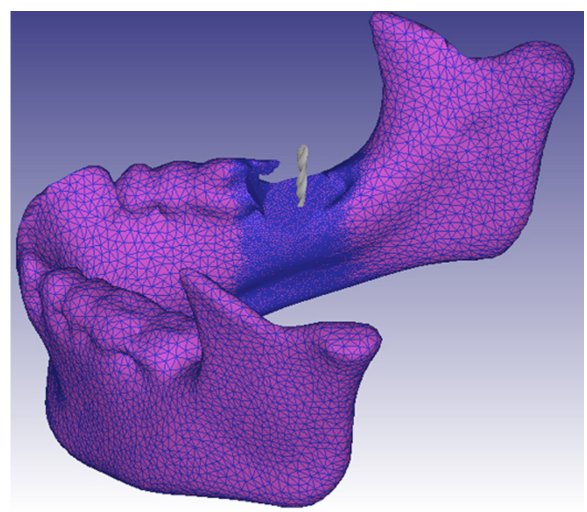

Fig. 2. Position of the drill bit on the software mandibular model.

where $\bar{\sigma}$, $\bar{\varepsilon}$, $\dot{\bar{\varepsilon}}$ and T are the flow stress, effective plastic strain, effective strain rate, and temperature, respectively.

We fed the data on cortical bone stress at 25 °C and the three strain rates of 1/S, 0.001/S, and 0.00001/S into the software (Fig. 1).[21]

At this stage of the process the model's meshing process begins. The elements are tetrahedral and number 110.991 for the mandibular model with a total of 25.241 nodes (Fig. 2). To increase the accuracy of simulation, the size of meshes at the drilling site are finer. An elastic-plastic material is assumed for predicting the behaviour of cortical bone in the mandibular model.[22] The calculated moving boundary conditions for the mandibular model are such that the external portion of the mandible is fixed, except for the drilling region. Here the