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Experimental investigation of the temperature during bone drilling using thermocouples and numerical finite element analysis

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Abstract

The purpose of this study was to experimentally measure and simulate thermal diffusion in the surrounding of specific dental drills with cylindrical and conical drills. The temperature generated under different drilling conditions with and without cooling and at different irrigation speeds. During the experimental measurements, a 2-mm diameter drill was used to drill through a 2-mm thickness of artificial cortical bone, and three different irrigation speeds, 800 rpm, 5,000 rpm and 5,000 rpm. Finite element method (FEM) simulation of the thermal diffusion during drilling in the PUR bone was also performed. As a result, different temperature diffusion was found in the surroundings of the individual drills. During specific drilling conditions, some of the drills produce higher heat than as opposed to the other tested drills. The results from the numerical FEM analysis are consistent with the experimental results. The temperature rise in the bone was found to be conditions after the results. The measurement of the temperature under different specific conditions that resembled mechanical drilling and did not match the reality of drilling in dental surgery, which is only intermittent and the drilling force is reduced by the dentist's hand. The actual temperature is probably much lower than the results presented in this experimental study. The results can be used for unique optimization of the drill and the irrigation for better bone temperature.

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Introduction

During machining, heat is generated in three ways. First, plastic deformation occurs in the primary deformation zone in the shear plane. Local heating in the plane of shear is caused by the conversion of the mechanical energy into heat. In the secondary deformation zone, due to the exhaustion of the chip and other overcoming friction in the interface of the tool and chip. Finally, heat is created in the tertiary deformation zone, which is on the surface of the tool and workpiece and given by the work which serves to overcome the friction between the mechanical surfaces of the tool and the workpiece. The heat generated in the primary and first two zones are mainly affected by cutting conditions and the tertiary zone is the generator mainly influenced by wear of the tool [1].

The temperature of the temperature rise in the bone may cause heat consequences for good osseointegration and subsequent fixation of the implant. The limit temperature for bone necrosis is 47-10 °C for a period of 1 min. Experimental investigation of temperatures in in vivo bone/drills is difficult and almost impossible. Bone tissues remodeling due to stress, any artificial or unnatural stress [2, 3].

Temperature production during surgical drilling is influenced by various parameters, such as drilling speed, drilling force [1,5], the diameter of the drill [1,4], and drill wear [1,5].

A review of the most common experimental techniques for temperature measurement in metal cutting processes reveals that these techniques can be classified into three categories: tool-work thermocouple, infrared radiation and tool-work testing processes. The first two methods are the most common. Metallographic methods are based on an analysis of the microstructure of the cutting tool and they are a valuable only for a limited number of cutting tools. Available methods which can be used for temperature measurement are resistance methods, thermo-couples [16], and spectral radiation spectrometry [17].

The drilling operation provides only a limited access for infrared measurements of the bone temperature in dental drills. Hence thermal measurement is necessarily restricted to the outer surface of the workpiece where temperature is only obtained indirectly from the bone temperature [18].

Drilling in dental bone is a complex process with many variables and conditions. Dentists are trained to perform dental surgery in the most gentle way to avoid unnecessary damage to the bone. Bone tissue is very sensitive to thermal insult and by using an infrared camera to measure the temperature at the exit of the drill. Bernard, the workpiece, a 45° deviation mirror was used to direct the signal into the camera. Cooling systems were shown to reduce bone temperature.

Another possible experimental technique was invented by Pugeat et al. [19]. They used a device focused on monitoring chip formations during orthodontic anchored drills into T-alloy. Ultrasonically assisted drilling was used into the cortical bone [20].

Ocanto and Kuga [20] measured drill temperature by inserting standard thermocouples into the drill and measuring the temperature at the drill tip. The experiment employed about 6 rpm to keep the temperature data quickly and should work in wide temperature ranges. In this study, the temperature is measured by means of PTfe Teflon Coated K-thermocouples. Advantage bone temperature with a diameter of 127 μm. The thermocouple can take measurements up to 500 °C and its response time is 15 μs.

The key work for our purposes is a thermography measurement of the hole drilling residual energy by Varner et al. [21]. Surface infrared temperatures of the drilling mill and sample with small-gauge rosette of millimeter dimensions were determined. Results of the thermography measurements showed that the surface temperature field measurement is accompanying the strain measurement. Thermography step-by-step drilling. The temperature field is measured by the thermographic system Pro-Teme/CAR SC2000 with 320 × 240 resolution pixels of uncooled microbolometric detectors working in the wavelength band 7.5–13 μm and the accuracy ±2 K.

The factors that should be considered when choosing a temperature measurement technique are: measurement accuracy, response time, and the measurement temperature field influenced by the sensor, disproportionately to mass response time, and uniformity. These devices should be weighed against the following sensor cost of calibration, availability, and cost [15]. One of the further parameters which influence the heat production is drill speed [22].

Finite element simulations have been successfully used to model orthogonal metal cutting processes. They have significantly reduced the simplifying assumptions of the analytical models. However, the use of FEM in metal cutting research requires a large number of input parameters which need to be determined through an experimental procedure. Ozel and Zeren [23] developed a FEM-based predictive models for large deformation, high strain rate, temperature effects, tool-chip contact and friction models, and the separation criterion. Generally, application of finite element modeling in cutting processes involves two types of formulations: Lagrange or an updated Lagrangian. The analysis employs different material models, such as elastic-viscoplastic with strain hardening and the numerical solution exceeds for coupled thermo-mechanical models are also considered [23]. In other cases, the FEM analysis and experimental investigation of temperature during drilling into bone with specific surgical drill was carried [24].

Commercial implicit finite element codes such as Deform 2D-3D, MSC.Marc, Abaqus, ANSYS have volunteered by solving a heat generation model. Moreover, there is a lack of information about the thermo-mechanical properties of the bone. Moreover, temperature dependent, anisotropic and thermo-mechanically coupled Lagrangian finite element model specialized in machining operations. This software was used by Ozcelik and Bagci [28] for validation of experimental results. Temperature measurement during drill drilling.

For example, Biscaia et al. used the commercial FEM system Samcef Forge2 [27] for the fracture process modeling of long fibre composite drilling. This system employs the Arbitrary Lagrangian Eulerian method, which is based on the fracture process and more particularly on the computation of the energy release rate. It makes it possible to model the fracture process in the composite and to predict the influence of the geometry of the cutting tool on the fracture.

Lai et al. [28] used FEM-ABAQUS together with a new material constitutive equation for 1020 steel to simulate orthogonal machining with continuous chip formation. Deformation of the workpiece material is treated as elastic-viscoplastic with strain-rate hardening and the numerical solution exceeds for coupling between plastic deformation and the temperature field, including treatment of adiabatic shear instability. Ozel et al. [29] developed a finite element model using the Arbitrary Lagrangian Eulerian method, which is applied to find the heat partition on the tool-chip contact area and convection heat transfer coefficient of the cutting fluid. Ozel authors [28,31] used their own numerical model, mostly based on FEM, to solve various problems related to the material removal problem.

The aim of the experimental measurement in the present study was to verify the thermal diffusion differences in the surrounding of four specific dental drills during drilling into a polyurethane (PUR) foam block.

Materials and methods

The PUR material was taken from Sawbones Europe AB (www.sawbones.com). Sawbones Europe AB provides a wide range of standardized specimens that eliminate the variability encountered when testing with human cadaver bone. PUR foam provides consistent and uniform material with properties in the range of human cancellous bone. Relevant mechanical properties for comparison to human cancellous bone may depend on the particular test method that is being developed. The PUR foam is also used for medical devices, such as ASTM F1839-08 Standard Specification for Rigid Polyurethane Foam for Use as a Surgical Material for Testing Orthopaedic Devices and Instruments. They are primarily used for testing orthopaedic implants, instruments and instrumentation, and also for surgical drilling experiments [26].

Experimental setup

For our specific problem, thermography by an IR camera and thermocouples measurement was used.

The polyurethane (PUR) block (artificial bone) was 15x15x10 mm large with six holes of 2-mm depth for thermocouples thermocouples (see Figure 1). The holes for the thermocouples were distributed in a direction perpendicular to the drilling direction. These thermocouples measure thermal diffusion according to the drill depth and the PUR block. Thermocouples were fitted into the PUR block with silver thermo-paste for better temperature transmission between the PUR material and the thermocouples.

Figure 1. PUR block with designed holes for thermocouples in the direction perpendicular to the drilling direction.

The experimental setup consisted of a surgical drilling machine (Mikro) fixed in a three axis movement CNC machine. A PUR block with installed thermocouples for detection of the temperature rise in the bone was fixed in a table in the same horizontal axis as the surgical drilling machine, and in the drilling direction. In front of the PUR block, a thermal camera (FLIR) was installed for the temperature measurement during the surgical experimental drilling with different drill bits (Figure 2).

The experiment was realized at three different rotational speeds of 800, 5,000 and 5,000 rpm. In this investigation we did not use irrigation cooling [25]. Every measurement combination of a drill type and a rotational speed was tested with and without cooling. For cooling, the surgical drilling machine was used with cooling. The cooling medium was water. Cooling water was applied by showering on the surgical drill. The axial movement of a drill is one of the parameters [26,28]. In our case it was set at speed 30 mm/min, which was discussed with an experienced dentist. The drilling force of a dentist and drilling force were not investigated [32].

The experimental investigation was done based on four types of drills, two cylindrical and two conical drills from two different manufacturers.

1. Drill no. 10/10.5DB-Male Dental, cylindrical shape, diameter of 2.3 mm (Figure 2a).
2. Drill no. 10/10.5DB-A Dentsmart, cylindrical shape, diameter of 2.3 mm (Figure 2b).
3. Drill no. 10/10.5F-Male Dental, conical shape, minimum diameter of 2.1 mm and 10 mm maximum (Figure 2c).
4. Drill no. 10/10.5F-Male Dentsmart, conical shape, minimum diameter of 2.45 mm and 8.0 mm maximum (Figure 2d).

Figure 2. Different drills used in this study. Drill no. 10/10.5DB-Male Dental, Drill no. 10/10.5DB-A Dentsmart (b), Drill no. 10/10.5F-Male Dental (c), Drill no. 10/10.5F-Male Dentsmart (d).

FE analysis description

The aim of the created numerical 3D simulations drill geometries were analyzed. The drills were supplied by Male Dental (10/10.5DB-Male and 10/10.5F-Male) and two were supplied by Dentsmart (10/10.5DB-A and 10/10.5F-A). All drill geometries were scanned in 3D models with triangular surface mesh [33]. Thereafter, the drill models had to be reconstructed with the analytical surfaces. The geometry reconstruction was performed in the CAD software Rhinoceros. The deviation between the original triangular surface mesh and the analytical surfaces after geometry reconstruction was 0.05 mm. The reconstructed drill geometries are shown in Figure 3.

The geometry of the polyurethane (PUR) foam was designed as a solid cylinder with an outer diameter of 15 mm and height of 5 mm. The shape of the hole separating the drills surface shape was modelled in the axis of the cylinder. The depth of the hole was 5 mm.

Both the material models, the homogeneous and the isotropic, were used in all FE analyses. All material parameters were taken from the bone database MatWeb (www.matweb.com) and the PUR foam producer's website (www.sawbones.com) in manual [26]. The properties of the material properties are described in Table 1.

Table 1. Table of material properties for used stainless alloy 1.4313 and polyurethane foam [PUR].

	Material
Density	Steel
Specific heat capacity	Steel
Thermal conductivity	Steel
Young's modulus	Steel
Poisson's ratio	Steel
Coefficient of thermal expansion	Steel

In the experimental measurements and FE analyses, PUR foam was used because it is primarily used as an alternative test medium for human cancellous bone. These products are not intended to replicate the mechanical properties of human bone. However, it does provide consistent and uniform material with properties in the range of human cancellous bone. Relevant mechanical properties for comparison to human cancellous bone may depend on the particular test method that is being developed. PUR foam is also used for medical devices, such as ASTM F1839-08 Standard Specification for Rigid Polyurethane Foam for Use as a Surgical Material for Testing Orthopaedic Devices and Instruments. They are primarily used for testing orthopaedic implants, instruments and instrumentation, and also for surgical drilling experiments [26].

Simulation descriptions and mesh

The aims of the FE simulation were heating analyses of the drill and the PUR foam. The FE analyses were performed with a temperature dependent the alloy drill and the PUR foam. All analyses were defined in solid, coupled thermal displacement simulations with nonlinear contact definition [34].

Both parts of all the models were meshed by tetrahedrons with an additional degree of freedom associated with temperature. The drills were meshed by tetrahedrons with global size of elements 0.5 mm. Mesh refinement was heated by elements with the global size of elements 0 mm and the contact surface inside the hole was meshed by the mesh with the size of 0.1 mm.

Loads, interaction and boundary descriptions

The analyzed models were loaded by directed displacement and rotational boundary conditions. The FE analyses were set up in two consecutive steps corresponding with the experiments carried out. The drills were loaded by a rotational speed of 0.0047/0.0 mm corresponding with 800 rpm) and rotation angle (4t, = 1.51 rad 28°). The size of the displacement is corresponded with the drill and movement during drill rotation about 30°. In all the analyses, drilling speed of 800 rpm was used. The bottom surface of the PUR foam was fixed in all directions.

Heating of the drill was applied by the contact between drills and the PUR foam. The contact was defined using the hole surface and the outer drill surface. The contact formulation was a mixed contact, with the friction coefficient dependent on temperature (see Table 1). The produced heating was distributed evenly to both parts. The initial temperature at the beginning of the numerical simulation in all parts was set to 37 °C.

Results

Experimental results

The data obtained from the drilling experiments are presented in Table 2 for dry drilling without cooling and in Table 3 for water cooled drilling. The temperature in the PUR block was measured by the thermocouples and the temperature measurement at 2.5 mm distance from the drilling axis were monitored. The distance of each thermocouple was 1, 2, 3, 4, 5 and 6 mm from the incoming face of the drilled specimen (the face of the rectangular parallelepiped, where the drilling process starts).

Table 2. Experimentally detected temperature of four different drills during three rotational speeds.

	Drill 1	Drill 2	Drill 3	Drill 4
800 rpm				
5,000 rpm				
5,000 rpm				

Table 3. Experimentally detected temperature of four different drills during three rotational speeds.

	Drill 1	Drill 2	Drill 3	Drill 4
800 rpm				
5,000 rpm				
5,000 rpm				

The results showed that Drill 3/10.5F-Male Dentsmark (conical 3) cooled at speed at 800 rpm together with water measured at 30 minutes with or without cooling. The drill stopped in the hole, so the experiment was not finished.

The best heated specimen was the conical drill no. 10/10.5F-Male/Dental. It was measured at 5,000 rpm without cooling. The temperature rise was 25 °C above the surrounding of the drill, the maximum temperature was 50 °C, and at the cooling edge, it was 36.7 °C.

In both cylindrical drills, no 10/10.5DB-Male and 10/10.5DB-Dentsmark, very similar temperatures were detected. In the case with cooling, lower temperatures were in drill no 10/10.5DB-Male/Dental. In drill no 10/10.5DB-Dentsmark, a significant temperature was detected at the rotational speed of 5000 rpm in the surrounding of the drill in the case without cooling.

Results of original drills FE analyses

From the performed drills FE analyses, the temperature T (°C) distribution on the drills and PUR foam cylinder was obtained. Von Mises reduced stress σ_{eq} (MPa) distribution on the drills was observed as additional results. A summary of the numerical analysis results is shown in Table 4 and Figure 3a–d.

Figure 3. Figures of temperature T (°C) distribution on Male/Dental 10/10.5DB-drill (left) and PUR foam (middle), Von Mises reduced stress σ_{eq} (MPa) distribution on the drill (right).

Figure 4. Figures of temperature T (°C) distribution on Dentsmark/Male 10/10.5DB-drill (left) and PUR foam (middle), Von Mises reduced stress σ_{eq} (MPa) distribution on the drill (right).

Figure 5. Figures of temperature T (°C) distribution on Male/Dental 10/10.5F-drill (left) and PUR foam (middle), Von Mises reduced stress σ_{eq} (MPa) distribution on the drill (right).

Figure 6. Figures of temperature T (°C) distribution on Dentsmark/Male 10/10.5F-drill (left) and PUR foam (middle), Von Mises reduced stress σ_{eq} (MPa) distribution on the drill (right).

Table 4. Results from numerical analyses.

	Drill 1	Drill 2	Drill 3	Drill 4
Max temperature				
Max reduced stress				

Male/Dental 10/10.5DB: The Temperature T and Von Mises reduced stress σ_{eq} distribution on the drill are shown in Figure 3. The temperature and stress distribution are uniform on the drill and the PUR foam. The temperature and stress distribution are uniform on the cutting edge. The temperature distribution in the PUR foam is produced on the cutting tool signifying the heating edge on the cylinder surface. The maximal temperature is T_{max} = 51.1 °C on the drill and T = 52.7 °C on PUR foam in distance 2.5 mm from the drilling axis (see Von Mises reduced stress distribution on the drill is uniform and its maximal value is σ_{eq} = 206.7 MPa. The value of σ_{eq} is lower than the yield stress σ_y = 241.3 MPa. The value of σ_{eq} is lower than the yield stress σ_y of 241.3 MPa. It means the tool does not yield.

Dentsmark/10/10.5DB-A: The temperature T and Von Mises stress σ_{eq} distribution on the drill are uniform on the drill and the hole surface (Figure 3). The maximal temperature is T_{max} = 50.1 °C on the drill and T = 52.7 °C on PUR foam in distance 2.5 mm from the drilling axis. Von Mises reduced stress distribution on the drill is uniform and its maximal value is σ_{eq} = 206.1 MPa. The value of σ_{eq} is lower than the yield stress σ_y = 241.3 MPa. It means the tool does not yield.

Dentsmark/10/10.5DB-A: The temperature T and Von Mises stress σ_{eq} distribution on the drill are uniform on the drill and the hole surface (Figure 3). The maximal temperature is T_{max} = 50.1 °C on the drill and T = 52.7 °C on PUR foam in distance 2.5 mm from the drilling axis. Von Mises reduced stress distribution on the drill is uniform and its maximal value is σ_{eq} = 206.1 MPa. The value of σ_{eq} is lower than the yield stress σ_y = 241.3 MPa. It means the tool does not yield.

Male/Dental 10/10.5F: The temperature T and Von Mises stress σ_{eq} distribution on the drill are uniform on the drill and the hole surface (Figure 5). The maximal temperature is T_{max} = 50.1 °C on the drill and T = 52.7 °C on PUR foam in distance 2.5 mm from the drilling axis. Von Mises reduced stress distribution on the drill is uniform and its maximal value is σ_{eq} = 206.1 MPa. The value of σ_{eq} is lower than the yield stress σ_y = 241.3 MPa. It means the tool does not yield.

Dentsmark/10/10.5F: The temperature T and Von Mises stress σ_{eq} distribution on the drill are uniform on the drill and the hole surface (Figure 6). The maximal temperature is T_{max} = 50.1 °C on the drill and T = 52.7 °C on PUR foam in distance 2.5 mm from the drilling axis. Von Mises reduced stress distribution on the drill is uniform and its maximal value is σ_{eq} = 206.1 MPa. The value of σ_{eq} is lower than the yield stress σ_y = 241.3 MPa. It means the tool does not yield.

Discussion

It was found that the experimental method can be used for the measurement of the temperature distribution around the drill. The thermocouples sensors, which were placed in the drilled material, can give information about the temperature change during drilling. The results from the numerical simulations showed that maximum temperatures were found by the FE analysis of the drilling process during performing the PUR foam. This maximum temperature is close to the maximum which is probably inside the PUR foam during drilling.

The temperature obtained by using thermocouples was less than on the drill tip, but it was taken by different measurement methods. In all cases, the thermocouples were at a distance from the drill edge (drilled hole). The distance between the hole and the same for all thermocouple distributions was, and close to the drills with bigger diameters. Significant temperature differences were not found in different drill diameters.

Table 5 compares the results obtained from experimental measurements and from the FE analysis. The results from the FE analysis are higher than the results from the hole and were the same for all thermocouple distributions, and close to the temperatures along the drills measured by thermocouples and calculated by the numerical analysis. The results from the temperature measurements by the experiment corresponded to the calculated temperature. It is therefore possible to predict the temperature in the surrounding of the drill.

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Table 6. Maximal temperatures (°C) obtained from experimental measurements and FE analyses.

CSV Display Table

With the Dentamechanik 1610/914d-k conical drill, at 800 rpm and a displacement of 30 mm/min, there was a combination of cutting conditions where it was not possible to remove chips, the drill jammed, and the experiment could not be completed. The specific shape of this conical drill proved to be unsuitable in this case Numerical simulation in this case showed a significant increase in temperature.

The created FE simulations analyze the influence of the drill geometry on the heat production during drilling (friction of the drill on PUR foam). Generally, drilling is a rather complicated process, where multiple factors act (material removing, chip transport, drill geometry, drill size, cutting-face cooling, etc.) [4,39,40]. All the created FE analyses were focused only on one of them, on the heat produced by drill friction on PUR foam. We used our experience with numerical simulation of drilling to achieve a number of experimental and numerical results [38].

The FE analysis of this complex process is extremely difficult, especially when biological tissues are involved in this process (for biological tissues, it is impossible to import all necessary material properties to the FE model). Therefore, PUR foam with exactly defined material properties was used for the experimental tests and numerical simulations. In our opinion, this simplification did not influence the presented results in case of comparison of the used specific drills. The maximum temperatures estimated by the FE analysis correspond with the results obtained by the IR camera.

The measurements in our experiment were performed under specific conditions that resembled mechanical drilling and did not match the reality of drilling in dental surgery, which is very often interrupted, and the drilling force is reduced by the dentist's hand. The actual temperature is probably much lower. The FE analysis of temperature rise during drilling can be useful for shape optimization of the drill when the target function is lower in temperature [41] or for new drill shapes and function [42].

Unlike just measuring the temperature around the drill [43], we measured the temperature at the drill tip with an IR camera. Thus, we showed that this temperature is much higher, although it is not possible to measure inside the material, since it is not possible to rely only on thermocouples.

In our study it was shown that it is possible to simulate the formation of temperature when drilling into porous material, and to predict the suitability of the shape of the drilling tool so that the temperature did not rise above the limit of bone necrosis.

Conclusions

Experimental measurement of the drill temperature during drilling is difficult for many reasons. In our study, we experimentally measured the temperature around the drill with thermocouples and by using an IR camera during PUR foam penetration by the specific drill. In the numerical FE simulation of drilling under different cutting conditions, we achieved agreement with the experiment in determining the temperature. It is therefore possible to use numerical simulation of drilling for preliminary analysis of temperature conditions, without complex experimentation. We have shown that this methodology is suitable for assessing the shape of newly developed drills and we can reveal risk points in their shape. And finally, relatively small differences in the shape of the drill can mean large differences in temperature production.

Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability statement

Data about the article are available at DOI: 10.6084/m9.figshare.14173457

Additional information

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References

1. Jam J, Fard VN. A novel method to determine tool-chip thermal contact conductance in machining. Mater Sci. 2011;3:8491–8501. [Google Scholar]
2. Sousa JrC, Kelly CA, Moreira MRV, et al. β-SiSiN4 cutting tools obtaining for machining of the gray cast iron. In: Kuljanic E, editor. AMSTPS Advanced Manufacturing Systems and Technology. CISM International Centre for Mechanical Sciences (Courses and Lectures), vol. 486. Vienna: Springer; 2005. [Crossref], [Google Scholar]
3. Davies MA, Yoon HW, Schmitz TL, et al. Calibrated thermal microscopy of the tool-chip interface in machining. J Mach Sci Technol. 2003;7(2):167–190. [Taylor & Francis Online], [Web of Science ®], [Google Scholar]
4. Augustin G, Davila S, Mihoci K, et al. Thermal osteonecrosis and bone drilling parameters revisited. Arch Orthop Trauma Surg. 2008;128(1):71–77. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
5. Augustin G, Zigman T, Davila S, et al. Cortical bone drilling and thermal osteonecrosis. Clin Biomech (Bristol, Avon). 2012;27(4):313–325. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
6. Udiljak T, Ciglar D, Skoric S. Investigation into bone drilling and thermal bone necrosis. Adv Prod Eng Manage. 2007;2:103–112. [Google Scholar]
7. Stelzle F, Frenkel C, Riemann M, et al. The effect of load on heat production, thermal effects and expenditure of time during implant site preparation – an experimental ex vivo comparison between piezosurgery and conventional drilling. Clin Oral Impl Res. 2014;25(2):e140–e148. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
8. Gehrke SA, Bettach R, Taschieri S, et al. Temperature changes in cortical bone after implant site preparation using a single bur versus multiple drilling steps: an In Vitro Investigation. Clin Implant Dent Relat Res. 2015;17(4):700–707. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
9. Eriksson RA, Adell R. Temperatures during drilling for the placement of implants using the osseointegration technique. J Oral Maxillofac Surg. 1986;44(1):4–7. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
10. Hillery MT, Shuaib I. Temperature effects in the drilling of human and bovine bone. J Mater Process Technol. 1999;92–93:302–308. [Crossref], [Web of Science ®], [Google Scholar]
11. Soriano J, Garay A, Aristimuño P, et al. Effects of rotational speed, feed rate and tool type on temperatures and cutting forces when drilling bovine cortical bone. Mach Sci Technol. 2013;17(4):611–636. [Taylor & Francis Online], [Web of Science ®], [Google Scholar]
12. Bachus K, Rondina M, Hutchinson D. The effects of drilling force on cortical temperatures and their duration: an in vitro study. Med Eng Phys. 2000;22(10):685–691. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
13. MacKelvie T, Ghasempoor A, Janabi-Sharifi F. Force and torque modelling of drilling simulation for orthopaedic surgery. Comput Methods Biomech Biomed Eng. 2014;17(12):1285–1294. [Taylor & Francis Online], [Web of Science ®], [Google Scholar]
14. Karmani S, Lam F. The design and function of surgical drills and K-wires. Curr Orthopaed. 2004;18(6):484–490. [Crossref], [Google Scholar]
15. Allan JW, Williams ED, Kerawala CJ. Effects of repeated drill use on temperature of bone during preparation for osteosynthesis self-tapping screws. Br J Oral Maxillofac Surg. 2005;43(4):314–319. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
16. Komanduri R, Hou ZB. A review of the experimental techniques for the measurement of heat and temperatures generated in some manufacturing processes and tribology. Tribol Int. 2001;34(10):653–682. [Crossref], [Web of Science ®], [Google Scholar]
17. Dörr J, Mertens T, Engering G, et al. In situ/ temperature measurement to determine the machining potential of different tool coatings. Surf Coat Technol. 2003;174–175:389–392. [Crossref], [Web of Science ®], [Google Scholar]
18. Pujana J, Rivero A, Celaya A, et al. Analysis of ultrasonic-assisted drilling of 66aNr. Int J Mach Tools Manuf. 2009;49(6):500–508. [Crossref], [Web of Science ®], [Google Scholar]
19. Alam K, Hassan E, Bahadur I. Experimental measurements of temperatures in ultrasonically assisted drilling of cortical bone. Biotechnol Biotechnol Equip. 2015;29(4):753–757. [Taylor & Francis Online], [Web of Science ®], [Google Scholar]
20. Özcelik B, Bagci E. Experimental and numerical studies on the determination of twist drill temperature in dry drilling: a new approach. Mater Des. 2006;27(10):920–927. [Crossref], [Web of Science ®], [Google Scholar]
21. Honner M, Litz P, Vantner M. Thermography analyses of the hole-drilling residual stress measuring technique. Infrared Phys Technol. 2004;45(2):131–142. [Crossref], [Web of Science ®], [Google Scholar]
22. Fialho JC, Fernandes PR, Eça L, et al. Computational hp-joint simulator for wear and heat generation. J Biomech. 2007;40(11):2358–2366. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
23. Abukhshim NA, Mativenga PT, Sheikh MA. Heat generation and temperature prediction in metal cutting: a review and implications for high speed machining. Int J Mach Tools Manuf. 2006;46(7–8):782–800. [Crossref], [Web of Science ®], [Google Scholar]
24. Basiaga M, Paszenda Z, Szewczenko J, et al. Numerical and experimental analyses of drills used in osteosynthesis. Acta Bioeng Biomech. 2011;13(4):29–36. [PubMed], [Web of Science ®], [Google Scholar]
25. Paszenda Z, Basiaga M. FEM analysis of drills used in bone surgery. Arch Mater Sci Eng. 2009;36:103–109. [Google Scholar]
26. Tu Y, Chen L, Huang C, et al. Finite element simulation of drill bit and bone thermal contact during drilling. 2008 2nd International Conference on Bioinformatic and Biomedical Engineering. 2008:1268–1271. DOI: 10.1109/ICBBE.2008.649. [Crossref], [Google Scholar]
27. Zitoune R, Collombet F, Lachaud F, et al. Experiment-calculation comparison of the cutting conditions representative of the long fiber composite drilling phase. Compos Sci Technol. 2005;65(3–4):455–466. [Crossref], [Web of Science ®], [Google Scholar]
28. Lei S, Shin YC, Incroper FP. Thermo-mechanical modeling of orthogonal machining process by finite element analysis. Int J Mach Tools Manuf. 1999;39(5):731–750. [Crossref], [Web of Science ®], [Google Scholar]
29. Li R, Shih A. Spiral point drill temperature and stress in high-throughput drilling of titanium. Int J Mach Tools Manuf. 2007;47(12–13):2005–2017. [Crossref], [Web of Science ®], [Google Scholar]
30. Filiz S, Ozdoganlar OB. A three-dimensional model for the dynamics of microendmills including bending, torsional and axial vibrations. Precis Eng. 2011;35(1):24–37. [Crossref], [Web of Science ®], [Google Scholar]
31. Strenkowski JS, Hsieh CC, Shih AJ. An analytical finite element technique for predicting thrust force and torque in drilling. Int J Mach Tools Manuf. 2004;44(12–13):1413–1421. [Crossref], [Web of Science ®], [Google Scholar]
32. Horak Z, Dvorak K, Zarybnicka L, et al. Experimental measurements of mechanical properties of PUR foam used for testing medical devices and instruments depending on temperature. Density Strain Rate Mater. 2020;13:4560. [Google Scholar]
33. Sarpaste M, Ghoreishi M, Jahangiroor T, et al. Modelling and optimisation of temperature and force behaviour in high-speed bone drilling. Biotechnol Biotechnol Equip. 2019;33(1):1616–1625. [Taylor & Francis Online], [Web of Science ®], [Google Scholar]
34. Sharawy M, Misch CE, Weller N, et al. Heat generation during implant drilling: the significance of motor speed. J Oral Maxillofac Surg. 2002;60(10):1160–1169. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
35. Alsibaqh AH. The significance of motor speed on heat generation during implant drilling (experimental study on bovine bone). RDENT. 2009;9(2):303–306. [Crossref], [Google Scholar]
36. Bogovič V, Svete A, Bajsić I. Effects of a drill diameter on the temperature rise in a bone during implant site preparation under clinical conditions. Proc Inst Mech Eng H. 2016;230(10):907–917. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
37. Mishra SK, Chowdhary R. . Heat generated by dental implant drills during osteotomy-a review: heat generated by dental implant drills. J Indian Prosthodont Soc. 2014;14(2):131–143. [Crossref], [PubMed], [Google Scholar]
38. Horak Z, Tichy P, Dvorak K, et al. Application of an arbitrary lagrangian-eulerian method to modelling the machining of rigid polyurethane foam. Materials. 2021;14(7):1654. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
39. Brisman DL. The effect of speed, pressure and time on bone temperature during the drilling of implant sites. Int J Oral Maxillofac Implants. 1996;11:35–37. [PubMed], [Google Scholar]
40. Abbas AAS, Abou-El-Hossein K. Investigation of drill bit temperature during automatic bone drilling. IJEMM. 2018;3(4):245–250. [Crossref], [Google Scholar]
41. Pandey RK, Panda SS. Modelling and optimization of temperature in orthopaedic drilling: an in vitro study. Acta Bioeng Biomech. 2014;16:107–116. [PubMed], [Web of Science ®], [Google Scholar]
42. Augustin G, Davila S, Udiljak T, et al. Temperature changes during cortical bone drilling with a newly designed step drill and an internally cooled drill. Int Orthop. 2012;36(7):1449–1456. [Crossref], [PubMed], [Web of Science ®], [Google Scholar]
43. Hou Y, Li C, Ma H, et al. An experimental research on bone drilling temperature in orthopaedic surgery. TOMSJ. 2015;9(1):178–188. [Crossref], [Google Scholar]

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