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Este ciclo de conferências teve início em 1986, com a realização do 1º Encontro Nacional de Análise Experimental de Tensões no LNEC, tendo-se seguido mais 8 encontros nacionais e 2 internacionais (10th e 15th International Conference on Experimental Mechanics) realizados em Portugal.

Este evento comemora os 30 anos deste ciclo de conferências sempre sob a égide da Associação Portuguesa de Análise Experimental de Tensões (APAET). Nesta edição do CNME2016 foram abordados os seguintes temas:

- Análise experimental e numérica em infraestruturas de transportes
- Desafios e Oportunidades na Experimentação em Hidráulica e Ambiente
- Experimentação em Termofluidos
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- Acústica e Vibrações
- Biomecânica e Biomateriais
- Caraterização de Materiais
- Comportamento de Estruturas
- Dinâmica de Estruturas
- Geotécnica e Geologia
- Mecânica de Fluidos
- Métodos Computacionais e Simulação Numérica
- Monitorização Estrutural
- Nanotecnologia
- Tribologia

Neste suporte digital estão incluídos os artigos que, após terem sido sujeitos a um processo de revisão, foram aprovados pela Comissão Científica para apresentação no CNME2016.

Uma palavra final de agradecimento a todos os que permitiram a realização do congresso, com votos de um seminário proveitoso para a comunidade técnica e científica.

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EXPERIMENTAL STUDY OF TEMPERATURES DURING DRILLING OF EX-VIVO BOVINE BONES

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ASTRACT

The thermal bone necrosis induced during a drilling process is a frequent and potential phenomenon, which contributes to post-operative problems. The frictional heat generated from the contact between the drill bit and the hole wall is unavoidable. However, understanding advanced techniques for acquiring reliable thermal data on bone drilling is important to ensure the quality of the drilled hole. The purpose of this study is to present two different experimental methods to analyse the drilling conditions that generate the lower temperatures, avoiding the occurrence of thermal bone necrosis. Ex-vivo bovine bones were used to simulate the drilling process considering the effect of drill bit diameter, drill speed and feed-rate. Different experiments were performed to assess the repeatability of the tests. The results identified the drill bit diameter as the most critical parameter for inducing higher temperatures in bone drilling.

Keywords: Ex-vivo bovine bone / Drilling / Temperatures / Thermocouples / Infrared camera

1. INTRODUCTION

Due the increase of ageing population and the prevalence of bone diseases, bone drilling has become one of the most common medical interventions in medicine, especially in oral surgery and orthopaedics where it is widely used for correcting bone fractures, screw and prosthetics placement and surface preparation for joint fusion (Staroveski et al. 2015; Augustin et al. 2012). During drilling operations, the surgeon must apply an appropriate axial force to ensure the hole drilling stable and smooth (Hou et al. 2015). However, it is unavoidable the frictional heat due to the contact between cutting tool and the bone fragments, as well as the mechanical damage due to the larger and uncontrolled drilling forces. Due the lower thermal conductivity of the bone tissue, heat dissipation occurs slowly and the temperature from the drilling site can cause damage to the vicinity of the drilled hole. Many researches have shown that the temperature above a critical threshold over a corresponding period of time leads to the temporary or permanent loss of blood supplied to the bone and consequently leads to the death of the bone cells (osteonecrosis) (Tai et al. 2015; Augustin et al. 2009; Augustin et al. 2008; Hillery et al. 1999). This thermal damage may delay the process of healing, slowing the process of osseointegration and potentially resulting in implant mobility, which can significantly influence the post-operative recovery of the patients (Staroveski et al. 2015; Augustin et al. 2012; Karmani 2006).

The successful outcome of any drilling operation is directly related with the quality of the surgical technique, while minimizing associated injury to the surrounding tissue (Lee et al. 2012; Fernandes et al. 2015; Fernandes et al. 2016). A great number of drilling parameters are involved in the surgical operation of bone tissue. The most important parameters reported in the literature can be divided into two groups. The first group includes the drill bit specifications (drill diameter, geometry, design and wear) and the second one includes the drilling parameters (drill speed, feed-rate, drilling depth, pressure applied to the drill, variations in cortical thickness, bone density and the use of cooling) (Augustin et al. 2012; Pandey et al. 2013).

The influence of drill bit diameter, drill speed and feed-rate have been the subject of considerable attention in the literature. Many researchers carried out drilling tests to determine the effect of these parameters on the generated heat during the drilling of bone tissue with the goal to identify the parameters that prevent the osteonecrosis (Karaca and Aksakal 2013; Lee et al. 2012; Augustin et al. 2012; Augustin, et al. 2008; Benington et al. 2002; Kondo et al. 2000). Despite of great advances over recent years, most of these studies present conflicting conclusions that may be originated from the complexity of the problem and the great number of involved parameters.

In this study, conventional drilling was applied to fresh bovine bones to research the effects of drill bit diameter, drill speed and feed-rate on drilling heat through two different experimental methodologies. The experimental tests were performed in clinical and experimental environment using thermocouples and infrared thermography. The aim of this study is to examine the heat production through a qualitative analysis of the obtained results in *ex-vivo* bovine bones, for further information of the drilling conditions which will allow to help the health professionals, ensuring drillings within a safe zone and hence ensuring no thermal damage to bone tissue.

2. MATERIALS AND METHODS

Different methodologies and drilling tests are essential to find the best drill parameters and keep the bone damage to a minimum level. This study comprises two main procedures to evaluate the temperature rise with different drilling parameters: an experimental method conducted in clinical environment approaching as far as possible with a real surgery; and an experimental method conducted in laboratory environment with all controlled drilling parameters in a computer numerically machine.

The aim of the first method is to expand the knowledge of all steps involved in bone drilling and then implementing a controlled approach for temperature measurements, which includes accurate parameters. The experimental clinical method was carried out in Veterinary Hospital of UTAD (University of Trás-os-Montes and Alto Douro) using eight intact fresh femurs from bovine. The other experimental method was performed in Mechanical Laboratory at IPB-ESTiG (Polytechnic Institute of Bragança), which include the cortical part of the *ex-vivo* bovine femurs and a set of parameters to determine its effect on the measured temperature.

2.2. Bovine samples and preparation

Testing materials include fresh femurs from bovine animals as the closest animal bones to replicate the characteristics of human bone (Aerssens et al. 1998; Yuehuei and Robert 2000; Alam et al. 2009; Lee et al. 2012; Augustin et al. 2012; Hou et al. 2015). All samples were obtained from local butchers after the animal death, with ages between nine to twelve months. The bones used in the tests conducted in clinical environment were kept untouched and used within few hours after the slaughter to retain the mechanical and thermo-physical properties of bone (Fig. 1).

Fig. 1 - Fresh bovine bones

In the experimental method conducted in laboratory, tests were performed few days after obtaining the bone samples. In this case it is important to prepare the femurs correctly and keep their properties until the day of the tests. In order to maintain the mechanical and thermo-physical properties, *ex-vivo* bone samples were prepared according to the guidelines established by Yuehuei and Robert. (2000). All samples were maintained in saline solution with gauze swabs and kept stored in plastic bags at -4 ºC. Before the tests, frozen samples were thawed at room temperature for 24 hours.

As the part that produces higher temperatures is the cortical tissue, bovine femurs were cut into cylindrical samples with approximate length of 130-140 mm and an average thickness of cortical wall of 7-9 mm. The periosteum and bone marrow were removed leaving only the cortical bone tissue (Fig. 2). In total twelve specimens were prepared and each one could accommodate around six holes.

Fig. 2 - *Ex-vivo* bone specimens cut from middle diaphysis

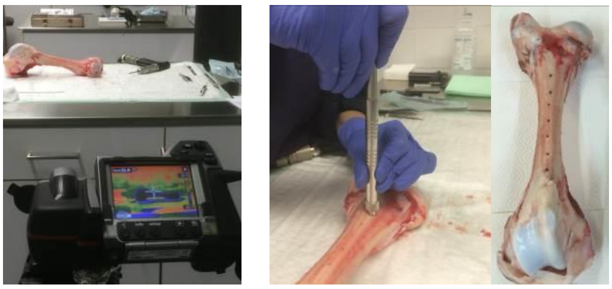
2.3. Experimental conditions in clinical environment

In order to obtain the closest as possible to the clinical conditions, holes were performed by one surgeon for one operative standardization. All drilling holes were made with a ComPact Air Drive II (DePuy Synthes, Inc., USA), using a conventional HSS twist drill bit with 4 mm of diameter and point angle equal to 118º. The air-driven power tool is a compressed air powered system used for treatment in orthopedic and traumatology surgery that allows a maximum drill speed of 900 rpm. Each bovine fresh bone received six holes with 20 mm of distance between them (Fig. 3).

(a) (b)

Fig. 3 - Clinical environment: (a) marking of the holes and (b) drilling process

The temperature was measured through a thermographic camera (ThermaCAM 365, FLIR Systems) which was rigidly fixed to a tripod at a distance of 1.5 m from the drill bit, as shown in Fig. 4. This method allowed to obtain thermal images of the bone and drill bit surfaces, before and immediately after drilling. Temperatures were measured in real time and the thermal image data were transferred to a PC for simultaneous analysis in appropriated software (FLIR QuickReport Software, FLIR Systems). All measurements started from room temperature, approximately 22 ºC and the bone temperature equal to 15 ºC. Between the successive experiments, sufficient time was allowed for the bone and the drill bit returned to the initial conditions.



(a) (b)

Fig. 4 - Experimental setup: (a) thermographic camera and (b) measuring of the holes depth

In order to obtain the feed-rate of each drilled hole, drilling time and hole depth were measured with an appropriate depth gauge. The average of feed-rates in each bovine femur was calculated and the values are represented in Table 1.

Table 1 - Mean values of feed-rates

Fresh bovine femurs	Feed-rate (mm/min)	
	Mean ± SD	(Range)
1 (n=6)	17.40 ± 2.07	[15.00-20.00]
2 (n=6)	27.40 ± 4.89	[23.44-36.00]
3 (n=5)	35.95 ± 8.40	[30.83-52.50]
4 (n=6)	43.44 ± 1.08	[42.27-45.00]
5 (n=6)	49.70 ± 2.03	[47.50-51.04]
6 (n=6)	59.02 ± 3.99	[52.50-63.00]
7 (n=6)	57.34 ± 6.27	[53.33-70.00]
8 (n=6)	61.92± 5.84	[55.00-70.00]

n number of the holes, *SD* Standard Deviation

2.3. Experimental conditions in laboratory environment

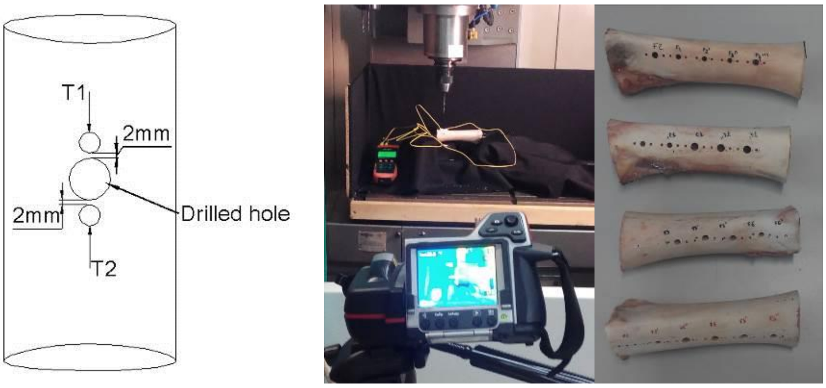
Experimental setup used in laboratory environment includes the temperature measurement system, CNC machine for a constant processing with controlled parameters, one drill bit with the same geometry used in the previous methodology and more two others tools with 5 and 6 mm of diameter.

A set of parameters was selected to investigate the effect of drill bit diameter, drill speed and temperature changes between different samples. The selection of the feed-rate and the drill depth were chosen through the means values obtained in the experimental clinical method. Table 2 shows the list of parameters under which drilling operations were performed. The combinations of parameters has been chosen considering the existing clinical practice based on hand-held drilling machines, as well as, the potential development of completely robotised drilling systems. Measurements for each combination of machining parameters were randomly repeated three times.

Table 2 - Parameters used in the experimental method

Parameters	
Drill speed, ω (rpm)	520, 900, 1370
Drill diameter (mm)	4, 5, 6
Hole depth (mm)	8
Feed-rate, V (mm/min)	18

For the temperature measurements, two methods were adopted. In the first method, the thermal camera was used in the same manner as in the previous method. In the second method, a datalogging thermometer (Extech SDL200: 4-Channel Datalogging Thermometer) was used for temperature monitoring inside the bone. Two K-type thermocouples (T1 and T2) were inserted into a hole (2 mm diameter and 4 mm in depth) and placed at distance of 2 mm from the edge of drilling track, in both opposite sides (Fig. 5 (a)). The distance was chosen in order to avoid crushing of thermocouples by the cutting edges of the drill bit. Thermocouples were fixed with adhesive mass to ensure the stability during the bone drilling. All drilled holes were carried out at room temperature. The distance between the holes and the cooling time of the drill bit were also considered as in the previous method. The drilling conditions were compared and the temperature mean values were calculated. The experimental setup used in this system is shown in Fig. 5 (b). All experiments were performed without irrigation at the drilling site.



(a) (b)

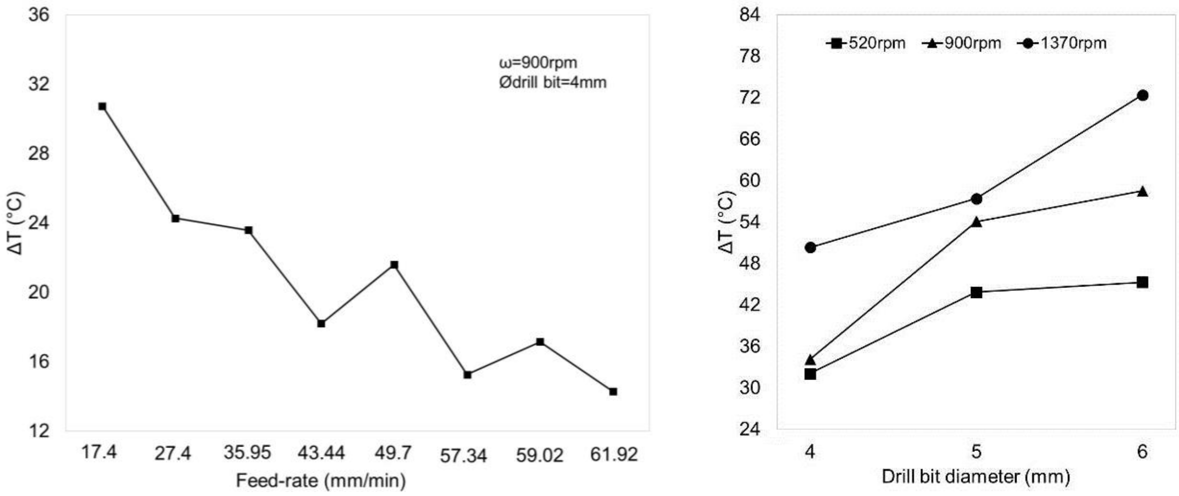
Fig. 5 - Laboratory environment: (a) K-type thermocouples position and (b) bone drilling

3. RESULTS AND DISCUSSION

3.1 Temperature variation in the drill bit

The recorded temperatures on the surface of the drill bit for the methods mentioned above are given under this section. In both procedures, temperature variation (ΔT) was calculated and compared, subtracting to the recorded temperature the initial temperature of the drill bit.

Results of the experimental method in clinical environment were summarized using mean values of temperature variation for each bovine femur and its respective feed-rate, as shown in Fig. 6(a). In the methodology conducted in laboratory environment, results were summarized using the mean values of temperature variation for all combinations of parameters (Fig. 6(b)).



(a) (b)

Fig. 6 - Temperature variation on drill bit in (a) clinical and (b) laboratory environment

Fig. 6(a) displays the resulting ΔT at different feed-rates subjected to a drill speed of 900 rpm and Ø4 mm HSS twist drill bit. Results show that there are significant temperature differences obtained in the different bovine femurs. From the Fig. 6(a) is possible to see that the ΔT in drill bit tended to decrease with increasing of feed-rate. The obtained results are in accordance with results founded by the authors Augustin et al. (2008), Lee et al. (2012) and Karaca et al. (2011). Another issue worth highlighting is that the bovine femurs have an irregular geometry with different cortical thickness along the femur. It was found that the holes made near of the bone extremities (epiphysis), with lower cortical thickness, had lower values of temperature, while the holes made in the medial area of the bone (diaphysis), with higher cortical thickness, had higher values.

This part of the study was used as references for drawing up the controlled method in laboratory, with results displayed in Fig. 6(b). In this case, three different drill bit diameters (4, 5 and 6 mm) and three different drill speeds (520, 900 and 1370 rpm) were considered. The feed-rate was kept constant at 18 mm/min. As shown in Fig. 6(b), maximum temperatures increase with the increasing drill speed and drill diameter, when all the others parameters are held constant. This trend has been noted from others experimental studies (Toews et al. 1999; Augustin et al. 2008; Hou et al. 2015). Comparatively, drill bit diameter has higher influence on increase of drill bit temperatures than drill speed. At lower drill bit diameter (4 mm), temperature did not achieve critical values.

3.2 Temperature variation in *ex-vivo* bone drilling

Through the thermocouples placed inside of bone, it was also possible to evaluate the temperature distribution along the drilling time, using the drill parameters mentioned above. The generated temperatures on the bone tissue at point 4 mm deep and 2.0 from the hole wall are presented in Fig. 7.

Fig. 7(a) displays the temperature history for the three different drill bit diameters as a function of the constant drill speed of 900 rpm and Fig. 7(b) displays the temperature history for the three drill speeds, as a function of the constant drill bit diameter.

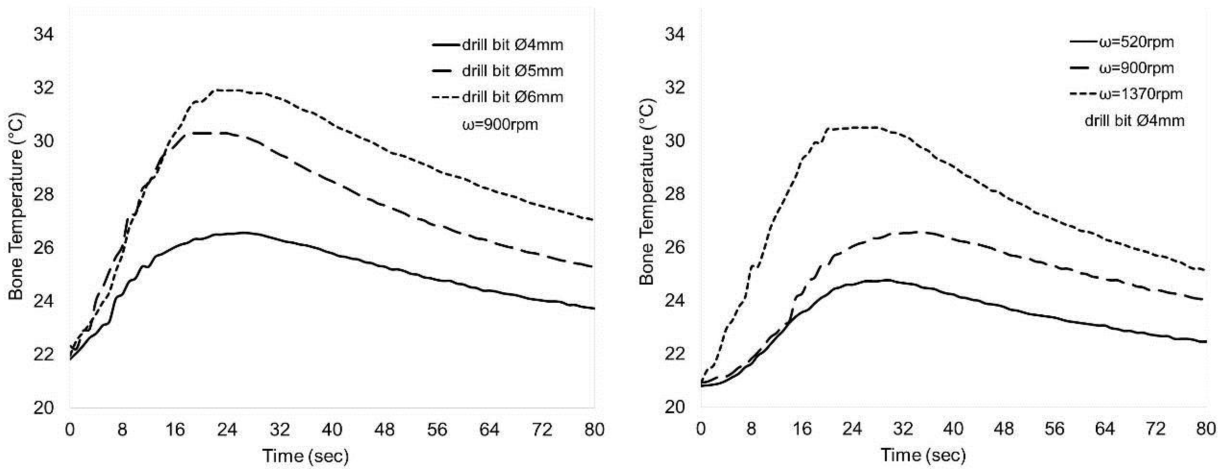


Fig. 7 - Bone temperature recordings with different (a) drill bit diameters and (b) drill speeds

Also inside of bone tissue can be observed that the maximum temperature increases with the increasing of drill speed and drill diameter. In Fig. 7(a), bone temperature increased 20.1% with increased drill diameter from 4 mm to 6 mm; and in Fig. 7(b), bone temperature increased 18.8% with increased drill speed from 520 rpm to 1370 rpm. The highest temperature values for higher drill speeds can be explained by the fact that the increase of drill speed increases the friction energy generation due to the friction forces acting on the rake face of the tool (close to the cutting edges). Since a majority of this energy is converted into heat, it is reasonable to expect an increased temperature at higher drill speeds, as it is supported by our results.

4. CONCLUSIONS

The temperature evolution on drill bit and bone tissue during drilling is crucial to improve the drilling surgeries. The drilling process involves heat generation, mainly in compact cortical bone. However, heat generation significantly varies among different bones from different species and even in the same species, due to the different properties and characteristics. For this reason, it is important to take account different techniques to analyze the temperature rise. This study experimentally investigated the effects of drill bit diameter, drill speed and feed-rate on the temperature elevation of drill bit and bone tissue during drilling. The conditions of the bone drilling in clinical and laboratory environment were assessed to find the drilling parameters that produce lower temperatures.

Results indicate that the temperature rise depends strongly on the drill bit diameter, drill speed and feed-rate. Higher temperatures were observed with the use of higher drill bit diameters, drill speeds and lower feed-rates. Drill bit diameter was observed to be the most critical parameter which induces higher temperatures in bone drilling.

In conclusion, both experimental methodologies demonstrated that the drill bit diameter, drill speed and feed-rate are essential parameters in the prediction of temperature rise, and therefore decreasing the incidence of osteonecrosis caused by heat in the surrounding cortical bone. In all tests performed were found temperatures far below the critical values. The appropriate control of drill conditions and the joining of the clinical and laboratory practice will allow to prevent the thermal necrosis and to improve the drilling surgeries.

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6. REFERENCES

Aerssens, J., Boonen, S., Lowet, G., Dequeker, J. 1998. Interspecies differences in bone composition, density, and quality: potential implications for in vivo bone research. Endocrinology, 139 (2), pp. 663–670.

Alam, K., Mitrofanov, A.V., Silberschmidt, V.V. 2009. Measurements of Surface Roughness in Conventional and Ultrasonically Assisted Bone Drilling, American Journal of Biomedical Sciences, 1, pp. 312-320.

Augustin, G., Davila, S., Udilljak, T., Staroveski, T., Brezak, D., Babic, S. 2012. Temperature changes during cortical bone drilling with a newly designed step drill and an internally cooled drill. International Orthopaedics, 36 (7), pp. 1449-1456.

Augustin, G., Zigman, T., Davila, S., Udilljak, T., Staroveski, T., Brezak, D., Babic S. 2012. Cortical bone drilling and thermal osteonecrosis, Clinical Biomechanics, 27(4), pp. 313-325.

Augustin, G., Davila, S., Udiljak, T., Vedrina, D.S., Bagatin, D. 2009. Determination of spatial distribution of increase in bone temperature during drilling by infrared thermography: preliminary report. Archives of Orthopaedic and Trauma Surgery, 129 (5), pp.703-709.

Augustin, G., Davila, S., Mihoci, K., Udiljak, T., Vedrina, D.S., Antabak, A. 2008. Thermal osteonecrosis and bone drilling parameters revisited. Archives of Orthopaedic and Trauma Surgery, 128 (1), pp. 71-77.

Benington, I.C., Biagioni, P.A., Briggs, J., Sheridan, S., Lamey, P.J. 2002. Thermal changes observed at implant sites during internal and external irrigation. Clinical Oral Implants Research, 13(3), pp. 293-297.

Fernandes, M.G., Fonseca, E.M.M., Natal, R. 2015. Three-dimensional dynamic finite element and experimental models for drilling processes. Proceedings of the Institution of Mechanical Engineers, Part L: Jornal of Materials: Design and Applications, p.1-9. DOI: 10.1177/1464420715609363 (In press)

Fernandes, M.G., Fonseca, E.M.M., Natal, R.J. 2016. Thermal Analysis during Bone Drilling using Rigid Polyurethane Foams: Numerical and Experimental methodologies. Journal of the Brazilian Society of Mechanical Sciences and Engineering, Springer, 0(0):1-9. DOI 10.1007/s40430-016-0560-4 (in press)

Hillery,M.T., Shuaib, I. 1999. Temperature effect in drilling of human and bovine bone. Journal of Materials Processing Technology, 92-93, pp. 302-308.

Hou, Y., Li, C., Ma, H., Zhang, Y., Yang, M., Zhang, X. 2015. An Experimental Research on Bone Drilling Temperature in Orthopaedic Surgery. The Open Materials Science Journal, 9, pp. 178-188.

Karaca, F., Aksakal, B. 2013. Effects of various drilling parameters on bone during implantology: An in vitro experimental study. Acta of Bioengineering and Biomechanics, 15(4), pp. 25-32.

Karaca, F., Aksakal, B., Kom, M. 2011. Influence of orthopaedic drilling parameters on temperature and histopathology of bovine tibia: an in vitro study. Medical Engineering and Physics, 33(10), pp.1221-1227.

Karmani, S. 2006. The thermal properties of bone and the effects of surgical intervention, Current Orthopaedics, 20(1), pp. 52-58.

Kondo, S., Okada, Y., Iseki, H., Hori, T., Takakura, K., Kobayashi, A., Nagata, H. 2000. Thermological study of drilling bone tissue with a high-speed drill. Neurosurgery, 46(5), pp. 1162-1168.

Lee, J., Ozdoganlar, O.B., Rabin, Y. 2012. An experimental investigation on thermal exposure during bone drilling. Medical Engineering and Physics, 34 (10), p. 1510-1520.

Pandey, R.K., Panda, S.S. 2013. Drilling of bone: A comprehensive review. Journal of Clinical Orthopaedics and Trauma, 4(1), pp.15-30.

Staroveski, T., Brezak, D., Udiljak, T. 2015. Drill wear monitoring in cortical bone drilling. Medical Engineering and Physics, 37, p. 560-566.

Tai, B.L., Palmisano, A.C., Belmont, B., Irwin, T.A., Holmes, J., Shih, A.J. 2015. Numerical evaluation of sequential bone drilling strategies based on thermal damage. Medical Engineering and Physics, 37, pp. 855-861.

Toews, A.R., Bailey, J.V., Townsend, H.G., Barber, S.M. 1999. Effect of feed rate and drill speed on temperatures in equine cortical bone. American Journal of Veterenary Research, 60(8), p. 942-944.

Yuehuei, A.H., Robert, D.A. 2000. Mechanical testing of bone and the bone-implant interface, New York: CRC Press, pp. 178-179.