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Induced Bone Tissue Temperature in Drilling Procedures: A Comparative Laboratory Study with and without Lubrication

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***Abstract*—**In orthopedic surgery there are various situations in which the surgeon needs to implement methods of cutting and drilling the bone. With this type of procedure the generated friction leads to a localized increase in temperature, which may lead to the bone necrosis. Recognizing the importance of studying this phenomenon, an experimental evaluation of the temperatures developed during the procedure of drilling bone has been done. Additionally the influence of the use of the procedure with / without additional lubrication during drilling of bone has also been done. The obtained results are presented and discussed and suggests an advantage in using additional lubrication as a way to minimize the appearance of bone tissue necrosis during bone drilling procedures.

***Keywords*—**Bone Necrosis, Bone Drilling, Thermography.

I. Introduction

BONE cutting and drilling are common orthopedic surgical procedures in the history of medicine. From among several clinical surgeries, knee arthroplasty can be referred to as the situation in which such a procedure is necessarily used in preparing the bone for the implant dimensions. Usually the surgery is performed without pain to the patient through loco-regional or general anesthesia and consists of, in a first step, providing the necessary exposure of the distal femur and proximal tibia. After this exposure, the surgeon carries out various actions of drilling and cutting the femur and the tibia using tools whose friction leads to a localized increase in temperature, and which may lead to the start of localized bone necrosis. There are several other clinical procedures with drilling preparation. The mounting of external fixators for bone fracture stabilization can be considered an example. Usually before screwing the pin to the bone in order to make the connection between bone and external fixation, the surgeon drills the bone side to side to mark, guide and help screwing the pin. Another typical situation is the clinical correction of bone deformities, such as the treatment of bunions. In this case the necessary bone cutting can be done percutaneously using specific drills in order to remove part of the bone and fix its new position.

In all cases involving the use of cutting and drilling tools there are a localized increase in temperature due to generated friction. The exposure of the bone tissue to heat causes denaturation of the enzymatic and membrane proteins, decreased osteoclastic and osteoblastic activity, dehydration, and desiccation, which may contribute to cell death. The bone itself is a poor conductor of heat with low thermal conductivity [1]. Thus, exposure of the bone tissue to elevated temperatures is an enhancer factor of the appearance of necrosis, observed histologically in a consistent manner when the bone is subjected to a thermal exposure exceeding 70° C over a period of time greater than 1 second [2]. According to [3], the process of necrosis may occur when the bone is exposed to a temperature above 50°C for 1 minute and at a temperature of 47°C for 5 minutes. Two studies show that bone temperature must be below the temperature of 47°C during the drilling process in order to avoid thermal osteonecrosis [4], [5].

In this work the authors proceeded to an experimental evaluation of the measured temperatures during animal bone drilling procedure. The study considers the use of fresh bovine bone and compares two scenarios: dry drilling and drilling using lubrication. The analysis of the results is exposed and shows a clear difference in maximal temperature measured when using the drilling procedure with auxiliary lubrication, which minimizes the probability of occurrence of thermal necrosis.

II. Experimental Procedure

The bone is a complex anisotropic biological tissue with organic and inorganic components. This fact makes it difficult to choose the ideal method for determining the bone temperature during drilling procedures. Generally there are two methods used for temperature measurement of bone during drilling: intrusive with thermocouples and non-intrusive with infrared thermography camera. Some articles have used both methods, where the images obtained from infrared thermography camera are utilized as a template to place thermocouples [6].

This experimental study involved the use of fresh bovine bone, a thermal infrared camera and an acquisition system with 4 thermocouples. A sort of fresh diaphysis bovine femur (with 100 mm length) have been prepared and stored at 23ºC. Each specimen was prepared according to Figs. 1 and 2, where

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the drilling position is defined in the thickest portion of the bone. Four small holes were then prepared with a 2mm depth and at a distance of 5 mm (T1, T3) and 10 mm (T2, T4) from the drilling position so as to position the 4 thermocouples (2 in longitudinal direction and 2 in cross direction).

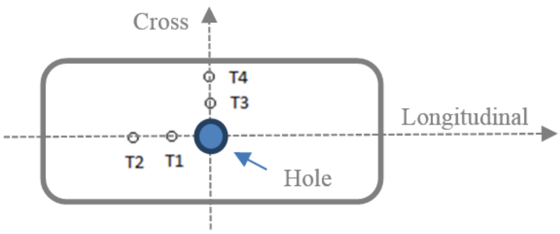


Fig. 1 Defined positions for thermocouple placement and drill

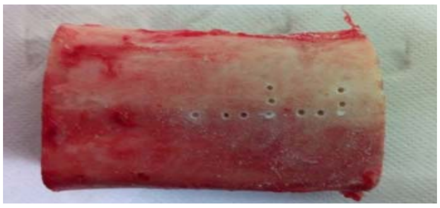


Fig. 2 Fresh bovine bone specimen with defined positions

The thermal infrared camera used in the experimental study was the Therma Cam Flir E300, showed in Fig. 3. The camera was positioned so as not to interfere with the drilling process and simultaneously take full advantage of the environment and light available. The measurement procedure was similar in all tests, namely the measurement distance, environmental conditions and lighting conditions. The use of this methodology minimized external interference. The accurate temperature measurement using infrared techniques requires knowledge of the emissivity that is the relationship between the amounts of infrared radiation emitted by a surface relative to a black body [7]. This property is of great importance, as it incorporates a direct way to quantify the energy emitted by the bone. In this study the value of emissivity was set to 0,98 [8].

Fig. 3 Therma Cam Flir E300

The acquisition system considers type K thermocouples and the temperature data were acquired using a National Instruments acquisition board, reference NI USB-9162, with a developed LabVIEW programming. Fig. 4 shows the front panel and the block diagram of the program.

In order to take control of the position and the speed of drilling process, a conventional milling machine was used. Fig. 5 shows the experimental setup considered where it can be observed the bone positioning system, the drilling machine and Therma Cam.

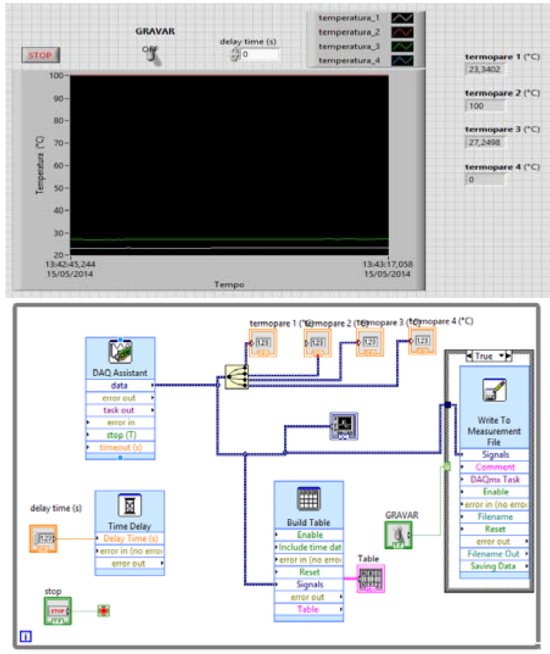
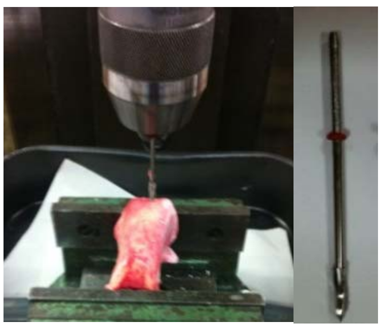


Fig. 4 Front panel and block diagram of LabVIEW program

Fig. 5 Experimental Layout



(a) (b)

Fig. 6 (a) Positioning in the milling machine; (b) Surgical drill

The experimental study considers a commercial surgical drill with a diameter of 2,74 mm. Fig. 6 shows a detail of the positioning in the milling machine and the surgical drill applied. The cutting speed of the milling machine was set to 710 rpm and the forward speed with the following possibilities: 0,26 mm/s; 0,66 mm/s; 1,04 mm/s; 1,66 mm/s.

The lubrication procedure was carried out in manual mode, as shown in Fig. 7 and refers to the use of a saline solution commonly used in surgeries.

Fig. 7 Lubrication procedure

III. Results and Discussion

Figs. 8 and 9 show examples of the thermography images collected without and with lubrication. In order to obtain more accurate results, a measuring window is defined with the same dimension for all tests. Thus, all data points fall into this space.

The images show the moment of maximum temperature for a single test in a specimen. As can be seen, the comparative procedures show a clear decrease in the maximum temperature when drilling procedure was made with manual saline lubricating.

Fig. 8 Example of a thermography image without lubrication collected at the maximum temperature

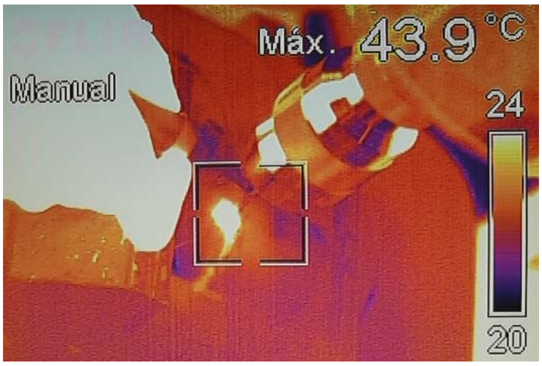


Fig. 9 Example of a thermography image with lubrication collected at the maximum temperature

Table I shows the mean result of maximum exposed temperature, the time duration with exposure temperature above 50ºC and the difference in maximum temperatures between dry and lubrication drilling procedures. The results are based on 5 experimental tests and are presented for all the forward speeds considered. As can be seen, the average of maximum temperature decreases with increasing forward speed. All the results show a high decrease in the maximum temperature when the lubricant procedure was used in the drilling procedure. Also, it can be seen that the maximum temperature reached with lubrication was always less than 37ºC.

Table II shows the mean results obtained with thermocouples. These results are presented only for the forward speed of 0,66 m/s. Comparing the results collected from thermocouples with those obtained with thermography, the maximum temperatures reached are lower for the measuring system with thermocouples. It should be pointed out that these results are consistent, since the measurements with thermocouples were made with 2 mm depth and 10 mm and 20 mm away from the center of drilling, as observed in Fig. 2.

Figs. 10 and 11 show the temperature registration in the thermocouples throughout the time. The graphs in the figures compare the two cases without lubrication and with lubrication for the forward speed of 0,66 m/s.

TABLE I
Results Obtained with Thermography

Forward Speed [mm/s]	0,26		0,66		1,04		1,66	
Lubrication	N	Y	N	Y	N	Y	N	Y
Tmax [ºC]	86,0±1,7	33,2±0,7	83,5±1,7	36,1±0,7	80,7±1,6	29,8±0,6	75,9±1,5	28,1±0,6
Decreasing Temperature [%]	52,8		47,4		50,9		47,8	
Time>50ºC [s]	43	0	28	0	18	0	9	0

Cutting Speed = 710 rpm

TABLE II
RESULTS OBTAINED WITH THERMOCOUPLES

Thermocouple	T1		T2		T3		T4	
Lubrication	N	Y	N	Y	N	Y	N	Y
Tmax [ºC]	50,7±0,4	29,7±0,3	28,8±0,2	23,8±0,2	59,8±0,5	42,2±0,4	26,8±0,2	25,1±0,2
Decreasing Temperature [%]	41,4		17,4		42,2		25,1	

Cutting Speed = 710 rpm ; Forward Speed = 0,66 m/s

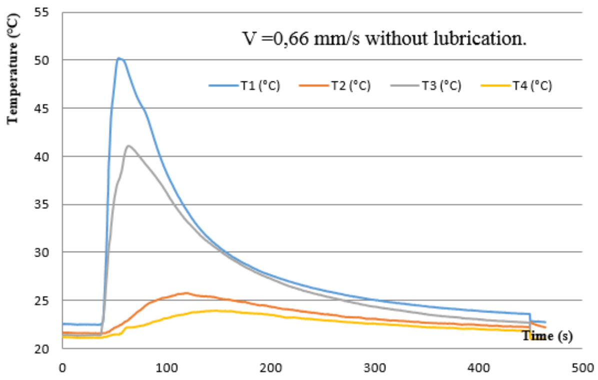


Fig. 10 Temperature - Time without lubrication

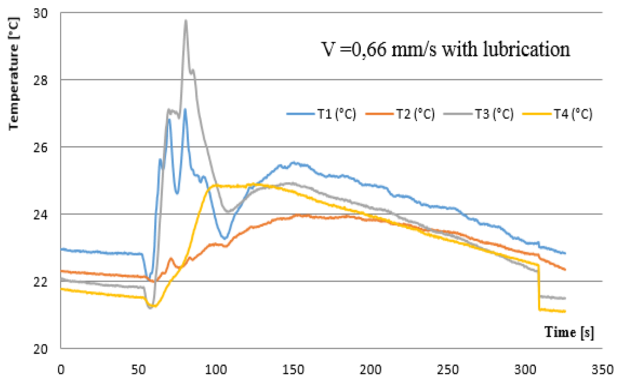


Fig. 11 Temperature – Time with lubrication

As can be shown in temperature – time evolution, the temperature was greater in the thermocouples next to the drill (T1 and T3). In the dry procedure, the registration of the highest temperatures occurred in the nearest thermocouple in the longitudinal direction. However, in the lubrication procedure, the highest temperature corresponds to the thermocouple in the cross direction next to the drilling tool. This inconsistency may be due to lubrication procedure, manually placed in the bone, with probably more saline solution in the cross direction.

IV. CONCLUSION

The results of this study show that temperatures obtained in the fresh animal bone during the drilling procedure exceed the amount shown as a reference to the likelihood of thermal necrosis. The study suggests that the introduction of additional lubrication can be an important way to reduce the appearance of necrosis during bone drilling procedures.

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REFERENCES

[1] S. Karmani, - "The thermal properties of bone and the effects of surgical intervention", *Current Orthopaedics*, Vol. 20: 52–58, 2006.
[2] A., Berman, J., Reid, J., Yanicko, G., Zimmerman, - "Thermally Induced Bone Necrosis in Rabbits. Relation to Implant Failure in Humans", *Clin. Orthop. Relat. Res.*, Vol. 186: 284-292, Jun 1984.
[3] J.,Lundskog, - "Heat and Bone Tissue", *Scand. Journal Plast. And Reconstructive Surgery*, Vol. 9: 1-80, 1972.
[4] R.,Eriksson, R., Adell – "Temperature during drilling for placement of implants using osseointegration technique", *J. Oral Maxillofac Surg*, Vol. 44:4–7, 1986.
[5] R., Eriksson, T. Albrektsson, B. Albrektsson, - "Heat caused by cortical one drilling. Temperatures measured in vivo in patients and animals", *Acta Othop Scand*, Vol.55: 629–31, 1984.
[6] V., Kalidindi, - Optimization of drill design and coolant systems during dental implant surgery, PhD thesis, University of Kentucky, 2004.
[7] F., Incropera, D., DeWitt, - "*Fundamentals of Heat and Mass Transfer*", John Wiley & Sons, ISBN 0-471-30460-3, 1996.
[8] L., Stumme, T., Baldini, E., Jonassen, J., Bach. - "Emissivity of Bone", Summer Bioengineering Conference, 1013-1014, June 25-29, Sonesta Beach Resort in Key Biscayne, Florida, USA, 2003.