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7th Portuguese Congress on Biomechanics

Guimarães – Portugal | 10th – 11th February 2017



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The Portuguese Congress on Biomechanics aims to promote and encourage the participation of the scientific and technical community of Biomechanics, in order to enhancing the progress and intervention of this field in Portugal.

In order to promote contacts between different research teams and to share the successes achieved, in 2005, it was held the 1st Portuguese Meeting on Biomechanics in Martinchel. Two years later, the 2nd Meeting was held in Évora elapsing with great success. Due to the natural evolution of these events, in 2009 the event name was changed to 3rd Portuguese Congress on Biomechanics, which took place in Bragança. In subsequent editions, in 2011 and 2013, the Portuguese Congress on Biomechanics took place in Coimbra and Espinho, respectively. Following the past events, the 6th Portuguese Congress of Biomechanics was held in February 2015 in Monte Real, Leiria

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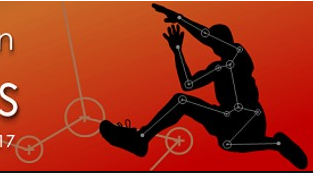
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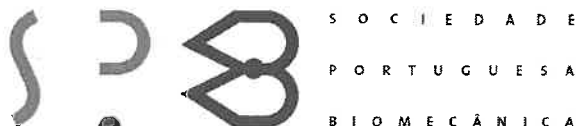
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EFFECT OF DRILL SPEED DURING DRILLING OF HUMAN CADAVERIC TIBIAE

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KEYWORDS: Drilling, Cadaveric Tibiae, Thermal Necrosis, Thermocouple

ABSTRACT: *Bone fracture is a feature of everyday life. Most of the treatments involve bone drilling to fixation of implanted medical devices. Bone loss due to excessive produced heat during drilling may weaken the purchase of surgically placed screws and pins, causing them to loosen postoperatively. Decrease the heat generation has a great demand as it helps in better fixation and healing of bone tissue. This paper presents an experimental model to study the effect of drill speed using human cadaveric tibiae. The results revealed that the temperature rise and the duration of temperature elevation decreased when lower drill speeds are used.*

1 INTRODUCTION

Bone drilling is a significant part of many medical interventions, including orthopaedic surgeries [1, 2]. Every day, millions of accidents happen involving bone fractures. In the United States alone, about 6.5 million automobile accidents happen annually resulting in femur or tibia fractures and other injuries [3]. The treatment normally requires drilling for screw placement, temporary bone fixation and surface preparation for joint fusion. However, the bone loss at the drilling site could negate any beneficial effects of this type of treatment. Recent studies have shown that the implant failure rate for lower leg osteosynthesis is 2.1–7.1% [4, 5]. One of the main causes of implant failures is the increase of the temperature during the process. Significant heat is produced during drilling due to the friction between the cutting surface of the drill bit in contact with the hole and bone fragments. When the

temperatures obtained during drilling operation reached the limit supported by bone tissue, thermal necrosis occurs. There are studies in the literature about to the temperatures recording during bone drilling that indicate thermal necrosis in cortical bone when this one reached of 47 °C for 1 min [6]. Other authors showed that temperature values above 55 °C for a period longer than 30 seconds can cause great irreversible lesions in bone tissue [7]. Finally, Eriksoon and Albrektsson [8] concluded that heating up to 47 °C could be considered as the optimal limit that bone can withstand without necrosis. The thermal necrosis to bone cells would delay the healing process after the surgery and reduce the strength of the fixation [9]. In order to minimize the damage caused by the high temperature and to improve this procedures, it is necessary to optimize the drilling parameters. Many researches have been

conducted to find out effects of different drilling parameters such as feed-rate, drill speed, drilling depth, drilling force and drill bit diameter. However, there is no general agreement about the effects of the drilling parameters under real conditions and most of the studies use animal bones, such as bovine, porcine or synthetic bones to replace the human bone [10-16]. To date, few researchers have actually employed human bone [7, 17-19]. Although the properties may be similar, drilling of human bone tissue might show a different response compared to animal models [20].

Recent studies on bone drilling has shown the importance of this subject. In fact, significant advances in surgical bone drilling research continue to be prepared, such as CO₂ pulsed laser drilling [21], haptic systems [19], teleoperation systems [22], among others. However, manual drilling widely persists in orthopedic clinical practice, which is a blind process with an unknown hole depth. In these cases, sensitive perception and accurate control of drilling forces are critical to the success of these procedures [23].

The aim of the present research was to measure the temperature rise from three different drill speeds using human cadaveric tibiae and relate the results to the operating drill speed. It was intended to present new findings relating the temperature rise in the human bone drilling under as close as possible to the real conditions.

2 MATERIALS AND METHODS

2.1 BONE SPECIMEN

The bone specimens used in this study were obtained from four non-embalmed human cadaveric tibiae (Fig. 1). There were two males and two females. The tibiae samples were obtained with the permission of the author's institutional research ethics board and were processed in the Body Donor's

Service and Dissection Room of the University of Barcelona.



Fig. 1 Human cadaveric tibiae samples.

The human samples were visually inspected to ensure no bone pathology and cut into sections from the medial condyle to the medial malleolus with a band saw. The average length of the samples was 236 mm with an average cortical thickness of 3.7 mm (Fig. 2).

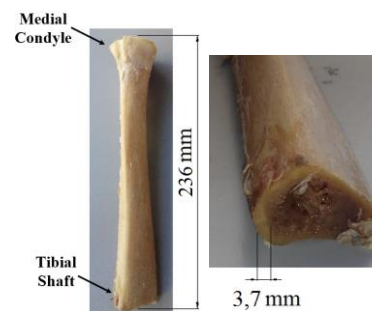


Fig. 2 Detailed view of human cadaveric samples dimensions.

Due to the limitation of the cadaveric bone sources, whenever possible, donor medical histories were accessed to verify the absence of bone pathology.

2.2 DRILLING SETUP

The experiments have been designed to study the effect of three different drill speeds in combination with the feed-rate and a constant drill diameter, and their interactions on the temperature rise were determined. Drillings were performed in the Mechanical Laboratory at Polytechnic Institute of Bragança.

Considering ten holes for each velocity, thirty experiments were made at drill speeds of 520, 900 and 1370 rpm. These velocities were chosen according to the speeds normally used in orthopedic surgeries. The

feed-rate was not controlled, since in orthopaedic practice this parameter varies from surgeon to surgeon. In this particular case there will also be a variation, since the drill is hand-held. All the other parameters were considered constant. To obtain the feed-rate for each drilled hole, drilling time and hole depth were measured with an appropriate depth gauge. The average of feed-rates for each drill speed was calculated and the values are represented in Table 1.

Tab 1 Mean values of feed-rates

Drill Speed	Feed-rate (mm/min)	
	Mean value	(Range)
520 (n=10)	15.77	[8.06-36.36]
900 (n=10)	14.30	[7.33-33.28]
1370 (n=10)	11.73	[7.21-14.86]

n number of the holes

A drill press machine with multiple speed control was used to execute the drilling operation on the human cadaveric tibiae. All tests were done using a twist drill bit with 4 mm of diameter and point angle equal to 118°.

The mean rise temperature, drilling time and the time needed for the bone samples to return the initial conditions were monitored using a datalogging thermometer (Extech SDL200: 4-Channel Datalogging Thermometer). Two K-type thermocouples (T1 and T2) with 2 mm of diameter were placed into a hole, as closely as possible to the drilled area (approximately 2-3 mm), in both opposite sides, as shown in Fig 3.

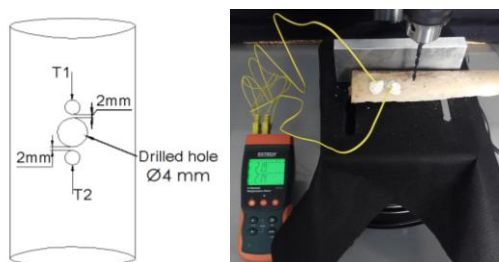


Fig. 3 K-type thermocouples position.

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.

The drill bit temperature was also monitored and controlled by a thermographic camera (ThermaCAM 365, FLIR Systems) which was fixed to a tripod at a distance of 1.5 m from the drill bit. 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).

The measurements started from room temperature, approximately 23 °C. All experiments were performed without irrigation at the drilling site. Between the successive experiments, sufficient time was allowed for the bone and the drill bit returned to the initial conditions.

The entire experimental setup is illustrated in the Fig. 4.

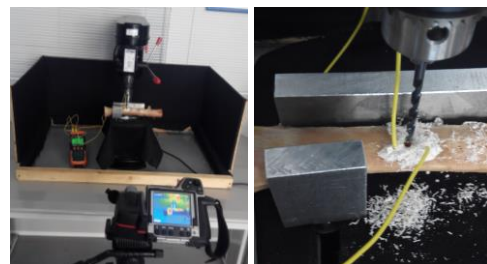


Fig. 4 Experimental setup for drilling bone tissue.

3 RESULTS AND DISCUSSION

In this work, a set of experiments were performed in order to study the effect of drill speed on the heat generated during drilling of human cadaveric tibiae. According to the best knowledge of the authors, very few studies has been reported on analysis of the effects of drill speed on the human bones. Furthermore, the varying experimental conditions and contradicting results make comparisons and difficult

conclusions. The present work includes temperature measurements with thermocouples inside of bone and temperature distribution visualization with a thermographic camera to analyse the heated surface in the drill bit. Fig. 5 shows the average of maximum bone temperature distribution inside of human cadaveric tibiae, considering each drill speed.

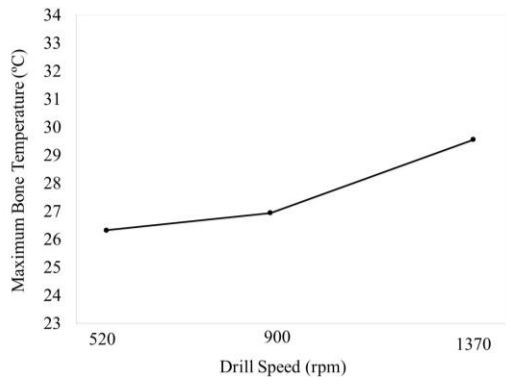


Fig. 5 Temperature evolution on human bone at different drill speeds.

As can be seen in Fig. 5, differences in temperature elevation during drilling were observed for the different drilling speeds. The highest drill speed together with smallest feed-rate leads to an increase of bone temperature during the drilling. The increase of bone temperature could be explained by the fact that the higher drill speed leads to an increase of the number of cuts and the amount of friction between the drill and the bone, thus leading to a higher accumulated friction energy and a higher bone temperature rise. These results are in accordance with those of recent studies, using animal models and artificial bones [13, 24].

Thermographic images were also taken from drill bit surface. The temperature variation (ΔT) was calculated for each drill speed, subtracting to the recorded temperature and the initial room temperature of the drill bit. Fig. 6 show the resulting ΔT at different drill speeds using an $\varnothing 4$ mm HSS twist drill bit.

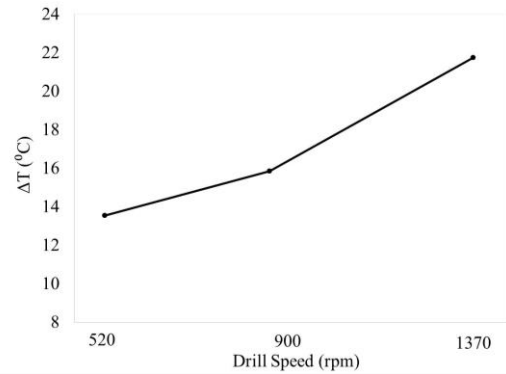


Fig. 6 Temperature variation on drill bit at different drill speeds.

Thermographic analysis showed that the growth in drill bit temperature also increased with the increase in drill speed. Another important feature which has been noted is that drilling process is much more compact and solid than bone marrow, bone marrow could be omitted as a tissue that causes resistance to drilling. The cortical bone tissue is hard and rigid, which causes resistance to drilling with subsequent friction and increase in bone temperature as the result of frictional heat [4].

4 CONCLUSIONS

The difficulty in measurements during bone drilling is a common knowledge due to complex nature of the bone tissue as well as the process itself. It is well know, that there is variation of the properties from samples taken from different bones species, outcome in variations of results, although subject to identical drilling conditions. In this way it is important, whenever possible, use human bones to ensure reliable results. This study experimentally investigates the effects of drill speed on the elevation of bone temperature during drilling in human cadaveric tibiae models. Within the restrictions of the present study, results showed that the bone drilling at 520 rpm generates less heat than at faster speeds. However, it should also be kept in mind that these experimental results were obtained *ex vivo*, under conditions that differ from clinical situations, that is to say, there was no blood flow and therefore, no

heat transfer to cool and hydrate the bone samples.

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