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# 7<sup>th</sup> Portuguese Congress on Biomechanics

Guimarães – Portugal | 10<sup>th</sup> – 11<sup>th</sup> February 2017



In Portugal, over the last decades, Biomechanics has contributed decisively to extending the frontiers of the knowledge, as result of the excellence research. It has led to the development of important applications with relevance in the fields of medicine, bioengineering, biology, sport, ergonomics, rehabilitation, accessibility, occupational therapy, among others.

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

Therefore, the Portuguese Congress on Biomechanics aims to be an open forum for the scientific community engaged in the work and research in various areas of biomechanics, to discuss and share the developed research.

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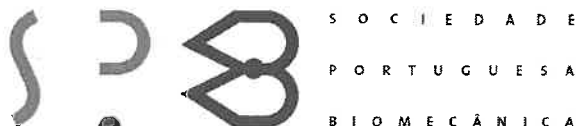
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## STRESS ANALYSIS DURING DRILLING OF HUMAN CADAVERIC TIBIAE

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**KEYWORDS:** Drilling, Cadaveric Tibiae, Stress, Strain Gauge

**ABSTRACT:** *Significant researches exist to estimate and to control the bone drilling temperatures, however no published data exist regarding the stress analysis during the bone drilling, mainly in the case of human bones. The inherent difficulties to this process and to collect human bones lead to a lack of information about this subject. The present study investigates the influence of drill speed on the stresses generation of human cadaveric tibiae. An experimental approach of bone drilling has been conducted using linear strain gauges on surfaces of bone tissue. It was concluded when the drill speed is lower, the level of stresses in the human cadaveric tibiae are lower.*

### 1 INTRODUCTION

Bone machining includes a number of procedures such as grinding, drilling, milling and sawing. All of them are very common in various surgical interventions [1]. The desired outcome of bone machining is to ensure the bone tissue integrity which leads to success of bone surgery interventions. Before performing those surgical procedures, it is crucial to study the bone drilling and its behaviour for supporting the implementation of appropriate cutting conditions and improve the quality and safety of these interventions. Specifically, the present work focuses on human bone drilling procedures, which is often used in orthopaedic surgery. Unfortunately, bone fracture is a common reality and can happen as a result of road accidents, falls, sports injuries, etc. Most of the treatments involve bone drilling to insert screws, wires and fixing plates, which enables the immobilization and alignment

of bone parts for proper healing [2, 3]. However, if it is not used accurately, especially in fixation procedures, may lead to the tool breakage, structural damage of the bone tissue and thermal necrosis [4-7]. Research on bone drilling has recently regained a lot of attention. Many experimental and computational studies have been made to assess the drilling parameters that influence surgical drilling into bone. To date, however, relatively few investigators have actually employed human bone [8, 9, 10]. The majority of published studies used bovine or porcine cortical bone of the diaphyseal layers as test material. Indeed, some animals can resemble the human properties but none of them is equal to the human bone. This inherent variation in mechanical and thermal properties of specimens taken from different bones results in differences in the results subject to virtually identical drilling

conditions in repeated experiments [11]. Also, most of the researchers have been focus their studies in determining the best drilling parameters (e.g. drill speed, feed-rate, hole depth, drill bit geometry or bone density) to prevent excessive heating and to limit the thrust pressure or drilling torque [1, 6, 7, 11-16]. There is a lack of information on the mechanical bone damage, especially about the strain and stress distribution in bone tissue during drilling and its surface integrity. Although in several methodologies have been proposed estimated values for bone temperature and cutting forces, none of them include the stresses distributions on the bone. In the literature, several techniques can be found to measure the strain level in body surfaces during the drilling processes for many industrial applications, but no application was found for medical situations. Usually, the strain level is measured using strain gauges and a data acquisition system from which the stresses can be calculated. Therefore, the importance of the drilling process on the mechanical damage for further patient evolution has motivated this study on human cadaveric tibiae.

In this study, an experimental model was developed to predict the level of strains and stresses during the drilling process of human cadaveric tibiae. A series of experiments under different drill speeds were conducted, in order to evaluate its effect on mechanical bone damage. Each human cadaveric tibia was instrumented with strain gauges in different surface positions during the drilling process.

## 2 DRILLING EXPERIMENTS

### 2.1 HUMAN TIBIAE PREPARATION

Three non-embalmed sections of human cadaveric tibiae were obtained with the permission of the author's institutional research ethics board. The tibiae samples were processed in the Body Donor's

Service and Dissection Room of the University of Barcelona. Human tibiae were stripped of soft tissues and then visually inspected to ensure no bone pathology (Fig. 1). Donor medical histories, when available, were accessed to verify the absence of bone pathology. The gender of the human cadaveric tibiae used in this work were 1 male and 2 females.



Fig. 1 Human cadaveric tibiae used in the study

Sections of the tibia from the medial condyle to the medial malleolus were cut with a band saw into segments of 209 mm length on average. The cortical tissue was measured with an average thickness of cortical wall of 3.5mm, as shown in Fig. 2.

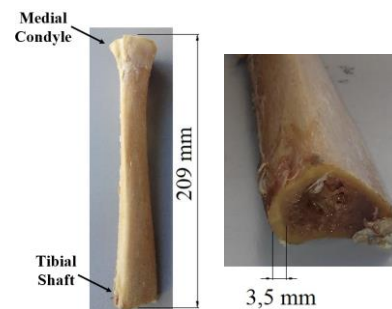


Fig. 2 Human cadaveric sample dimensions used for the drilling tests

### 2.2 DRILLING SETUP

It was decided that the most efficient method of measuring the strain level at the bone surface during drilling was to locate several strain gauges as close as possible to the drilled zone. Therefore, each sample was instrumented with three linear strain gauges (1-LY18-6/120,  $120\Omega \pm 0.35\%$  from HBM) to estimate the level of strain at the *facies medialis* flat tibial surface. To promote the strain gauge bond, the bone

surface was prepared by stripping of the periosteum in the area to which the strain gauge was applied. A small amount of adhesive was applied to the under surface of the strain gauge, which is then immediately placed in the prepared surface of the bone being careful to observe correct alignment. To promote the uniformity of results, all gauges were mounted in identical locations, considering the same distance of 3.5 mm between the hole and the strain gauge (Fig. 3).



Fig. 3 Human samples instrumentation

Wire leads were soldered to the strain gauge contacts and connected to an acquisition data system (Vishay Micro Measurements P3 Strain Indicator and Recorder). This system allowed to read the strains over time during each step of the drilling. The corresponding profiles of stresses in tibia surface versus drilling depth were calculated.

In order to investigate the effect of drill speed on the stresses generation of human cadaveric tibiae, the holes were performed on a vertical drilling machine with a twist drill bit ( $\text{\O}4$  mm and point angle of  $118^\circ$ ) and using three different drill speeds: 520, 900, 1370 rpm. The combinations of parameters have been chosen considering the existing clinical practice based on hand-held drilling machines. In clinical practice, the drilling operations are blind in nature with unknown hole depth and feed-rate. Therefore, our drilling tests were performed in the same way. However, all holes were carried out by the same operator, for one

operative standardization. All drilling parameters used in this study are summarized in Table 1.

Tab. 1 Parameters used in the drilling tests

Human tibiae	Drill speed (rpm)	Drill bit geometry
1	520	$\text{\O}4$ mm, $118^\circ$ point angle and $30^\circ$ helix angle
2	900	
3	1370	

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 in each human cadaveric tibia was calculated and the values are represented in Table 2.

Tab. 2 Mean values of feed-rates

Human tibiae	Feed-rate (mm/min)	
	Mean value	(Range)
1 (n=6)	23,88	[13,25-34,03]
2 (n=6)	19,49	[16,41-26,82]
3 (n=6)	14,45	[11,85-17,41]

*n* number of the holes

Temperature measurements of drill bit were also considered through a thermal camera (ThermaCAM 365, FLIR Systems). The camera was rigidly fixed to a tripod at a distance of 1.5 m from the drilling area and allowed to obtain thermal images of the drill bit surface, 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 tests were conducted from room temperature ( $23^\circ\text{C}$ ) without applying cooling at the drilling zone. The complete experimental setup for bone drilling is shown in Fig. 4. Measurements for each combination of machining parameters were randomly repeated six times.



Fig. 4 Drilling tests on cadaveric tibiae

### 3 RESULTS AND DISCUSSION

With three combinations of drilling parameters and six randomly performed measurements for each combination of parameters, eighteen readings have been extracted from all experimental tests. The results were divided into two groups. In first group, the drilling stress variation with drill speed. In second group, the temperature variation of the drill bit was presented according to the drill speed variation.

Fig. 5 shows the average of maximum drilling stress distribution on surface of human cadaveric tibiae, considering the variation of drill speed.

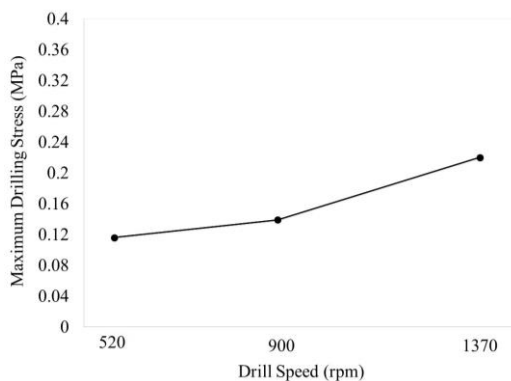


Fig. 5 Maximum drilling stress  $\sigma_{zz}$  (MPa) with drill speed.

It can be seen from Fig. 5 that the drilling stress increase with increasing of drill speed. Combining the Table 2 with the Fig. 5, it was also observed that the maximum drilling stress increase for the lowest values of feed-rate. Similar behaviour was reported in our previous studies using polyurethane foam materials with properties similar to the human cadaveric bone [17].

To display the relations of drilling speed and drill bit temperature, the temperature variation was calculated and compared subtracting the recorded temperature ( $T_R$ ) with the initial temperature of the drill bit ( $T_0$ ) for each hole ( $\Delta T$  ( $^{\circ}\text{C}$ ) =  $T_R - T_0$ ). The results were summarized using means values of  $\Delta T$ . Fig. 6 showed the result of  $\Delta T$  at different drill speeds and a drill bit of  $\text{\O}4$  mm HSS twist drill bit.

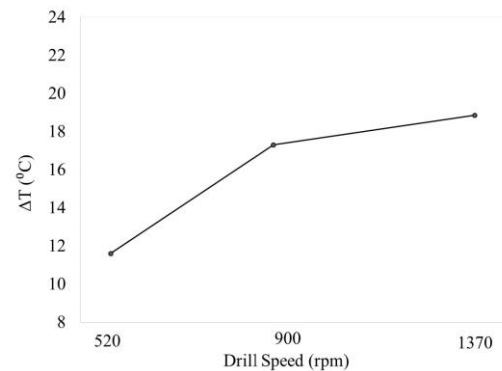


Fig. 6 The effect of drill speed on temperature variation of the drill bit.

It has further been demonstrated, through the Fig. 6, that the temperature variation on the drill bit increases with the increasing of drill speed. By carrying out this analysis, it can be expected that the bone temperature also increased with the increase in drill speed. One explanation for these results could be that the number of cuts and the amount of friction between the drill and the bone will be relatively increased, thus leading to a higher accumulated friction energy and a higher bone temperature rise. These outcomes are consistent with our already published works, using bovine and porcine bones [18]. In addition, other authors suggest the same results [19].

### 4 CONCLUSIONS

In this study, the effect of drill speed on the stresses generation of human cadaveric tibiae was investigated by using an experimental methodology. The parameters for the drilling tests included three drill speed and different feed-rates obtained by

the manual drilling, as it happens in clinical practice. Based upon the experimental results, the following conclusions are drawn:

-a drill bit with a lower drill speed can reduce the level of stresses and strains in the human cadaveric tibiae during drilling;

-the drill bit temperature and, consequently, the bone temperature increases as the drill speed increases;

-the stresses increase with the tool penetration and, consequently, with increasing of hole depth.

To summarise, in the clinical practice decreasing the rotation speed and increasing the drilling load, this also means, increase the feed-rate of the drill can shorten the friction time between the drill and bone, which reduces the friction heat, thereby reducing the rise in bone temperature and also the stresses and strains on human bone.

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