

In-Vitro Thermal-Vision Study of High Thermal Conductivity Drills Driven Without Liquid Cooling

Ramin Mirmooji¹, David Weatherall¹, Zvi Fudim^{1*}, Ziv Mazor¹

¹Founder of Stomatotech Inc. 4919, Boulevard Saint-Charles, Pierrefonds, Quebec, Canada

*Correspondence author: Zvi Fudim, Founder of Stomatotech Inc. 4919, Boulevard Saint-Charles, Pierrefonds, Quebec, Canada;

E-mail: zvifudim@gmail.com

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Abstract

The aim of this study is to review the thermal safety of drills made from high thermal-conductivity material (tungsten carbide), capable of absorbing the heat from the drilling site. In this study, 30 continuous drilling sessions of 40 seconds each were performed on a bovine rib, at 200, 400 and 800 RPM. A fresh bovine rib was used in ambient temperature between 26°C-30°C and the Flir One Pro LT thermal-vision camera (tolerance +/- 2°C) was used to measure the drilling temperature. Data analysis found a mean temperature increase of 4°C at 200RPM, 7.4°C at 400RPM and 16.4°C at 800 RPM with statistically significant differences. Previous studies suggest that a temperature increase greater than 10°C of bone can lead to peri-implant tissue inflammation and bone loss. The study also evaluates the dynamics of the temperature rise at each drilling RPM, after 10, 20, 30 and 40 seconds of continuous drilling.

Keywords: Thermal Conductivity; Liquid Cooling; Thermal Vision; Drilling

Introduction

Dental treatment by means of implant placement has become increasingly popular in recent years. The main goal of this approach is to provide the implant with the optimal condition for integration without inflammation of the surrounding soft and hard tissues. One of the main reasons for implant failure is thermal damage to the bone by the drilling process (50°C for one minute leads to bone loss and vascularity adjacent to the implant). At 47°C, there were histological differences from the normal bone. However, this is the safe temperature that is still quoted in some *in-vitro* studies [10-12].

One of the solutions to prevent the bone from being overheated is a liquid coolant (saline) [1-9]. This is insufficient in many cases, especially in cases of high-density bone (D1) according to Mish classification. Another drawback of liquid coolant is the wash out of the cellular content from the bone tissue which is essential for the healing and reparation processes of the implantation site [1].

What are High Conductivity Drills?

High-conductivity drills are made from tungsten carbide (WC) with a high thermal-conductivity coefficient (120 W/mK²) [2]. The higher the thermal conductivity coefficient, the higher the capacity of the material to absorb and exchange the heat [2].

Why Bovine Rib?

The bovine rib was chosen for this study since its cortical bone is much harder (4490 kg/m³) than the human mandible cortex (2200 kg/m³), thus the results of this *In-vitro* study can be safely applied on real osteotomy on a live human jawbone.

Methodology

A total of 30 drilling operations were performed on the superior and inferior sides of the ribs where a thicker cortical bone is found. The drilling sites were chosen randomly and the diameter of the drill was 4 mm. The duration of the drilling operations was set to 40 seconds, the minimum time required to drill 90% of the entire cortical bone regardless of the RPM. 10 drilling operations were drilled at 200RPM 10 drillings were drilled at 400RPM and 10 drilling operations were drilled at 800 RPM. The temperature was measured using a thermal-vision camera pointed at the drill bit as well as at the bone at the site of the drilling [10]. The temperature rise (ΔT) is the difference between the initial temperature (T_1) of the drill/ bone and the temperature at the end of the 40 seconds (T_2). The obtained data was statistically analyzed to determine the safety of the drills at 200, 400 and 800 RPM. Fig 1-4 represent the materials used in the study.



Figure 1: Fresh bovine ribs used to simulate mandibular 4 mm osteotomy. The bovine ribs were kept in a heated isotonic solution at ambient (26°C-30°C) temperature.



Figure 2: A 4 mm, high thermal conductivity drill. The drill was driven by a Dental surgical micro- motor equipped with a 20:1 re- duction implant contra-angle handpiece.



Figure 3: Flir One Pro LT thermal-vision camera (tolerance $\pm 2^{\circ}\text{C}$) mounted on a solid tripod used to measure the bone and the drill temperature [10].



Figure 4: An electronic scale was used to measure the constant force applied on the drill bit by the user.

Results

Table 1 Measured temperature values at axial force of 2.3 kg T1-initial temperature, T2- final temperature after 40 seconds of continuous drilling, ΔT difference between initial and final temperatures (Fig. 5) [6,7,9,11].

	200RPM 40 sec. 2.3 kg force			* 400RPM 40 sec. 2.3 kg force*			800RPM 40 sec. 2.3 kg force*		
	T1 ($^{\circ}\text{C}$)	T2 ($^{\circ}\text{C}$)	Δt_{200} ($^{\circ}\text{C}$)	T1 ($^{\circ}\text{C}$)	T2 ($^{\circ}\text{C}$)	Δt_{400} ($^{\circ}\text{C}$)	T1 ($^{\circ}\text{C}$)	T2 ($^{\circ}\text{C}$)	Δt_{800} ($^{\circ}\text{C}$)
1	26.3	31.3	5.0	26.5	34.0	7.5	28.3	44.2	15.9
2	30.1	33.8	3.7	27.0	35.0	8.0	30.1	43.8	12.9
3	28.8	33.3	4.5	26.4	34.0	7.6	28.7	42.5	13.8
4	29.2	33.5	4.3	26.5	36.0	9.5	29.0	52.0	23.0
5	30.5	34.0	3.9	28.4	36.7	8.3	29.5	45.0	15.5
6	30	32.5	2.5	29.0	36.0	7.0	30.0	46.5	16.5
7	29.3	33.0	3.7	29.5	37.3	7.8	29.5	44.3	14.8
8	29.3	33.2	3.9	28.5	35.8	7.3	29.2	42.2	13.0
9	27.5	32.0	4.5	31.0	36.7	5.7	27.8	42.5	14.7
10	30.0	34.0	4.0	31.0	36.0	5.0	30.0	53.5	23.5

Table 1: Measured temperature values.

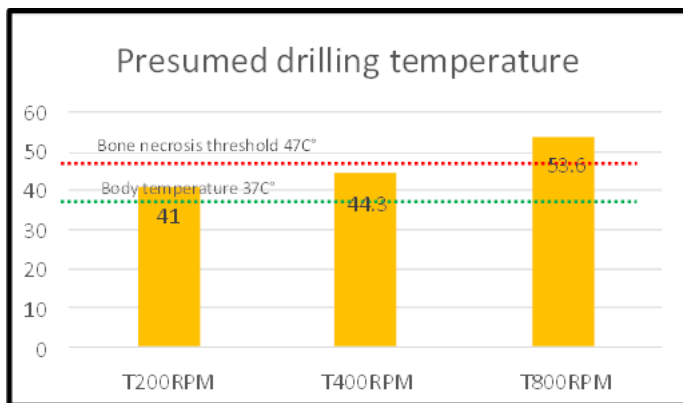


Figure 5: Presumed drilling temperatures in the patient mouth at 200, 400 and 800 RPM. Bone necrosis threshold 47°C [4]. Temperature measurement error is +/-2°C.

Temperature Dynamic Evaluation

For the dynamic evaluation, the drilling process was filmed with thermal-vision camera and temperature values were video recorded on the time axis after, 10, 20, 30 and 40 seconds at 200, 400 and 800 RPM. The obtained data was calculated and graphically expressed in Fig. 6, 7.

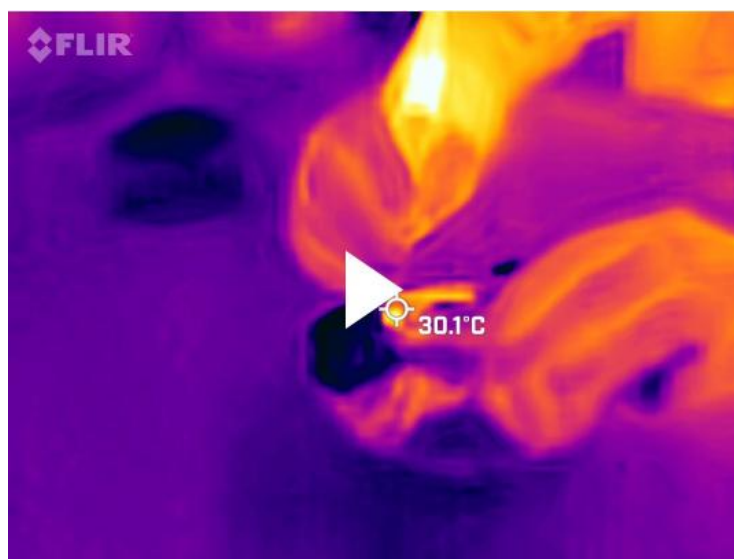


Figure 6: Video registration of the drilling using Thermovision camera Flir One Pro [10,11].

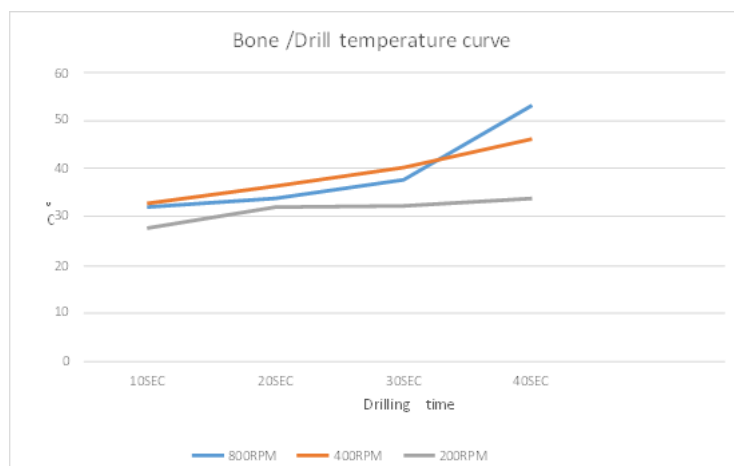


Figure 7: Dynamic analysis of drill temperature elevation rate [3,6].

Statistics: P-value from Z Score

High thermal conductivity drills used at slow speeds 200RPM³ did not exceed presumed 47°C ($\Delta T_{200} < 47^\circ\text{C}$), $p=0.00001$ at significance Level 0.05, Z score=9.44, which is considered a safety threshold in implant dentistry [4,12]. At 400 RPM ($\Delta T_{400} < 47^\circ\text{C}$) $p=0.014$ at significance Level 0.05, Z score=2.2, remains in the safe threshold [4,12].

However, there is a significant temperature rise (16°C) above 47°C at 800 RPM drilling ($\Delta T_{800} > 47^\circ\text{C}$, (At significance Level 0.05, $p=0.00001$, Z score = - 4.5) compared with 200 RPM drilling (4°C) at the end of 40 seconds of drilling [5].

Discussion

Temperature control of the bone is the key for successful implant integration [5,6]. The purpose of this study is to examine the safety of high thermal conductivity drills in the hardest working conditions, such as bovine rib using no liquid cooling (saline) [1]. When drilling to create an osteotomy, autologous bone chips and osseous coagulum, are created. When left in situ, because of their osteogenic properties, this valuable material promotes new bone formation. Once the bone chips are removed from the osteotomy by copious irrigation, cells quickly begin to die and so, even if retrieved, their osteogenic potential quickly deteriorates. Avoidance of irrigation use may be the solution to this problem [1,9].

The study also examined the differences in the temperature elevation rates ⁶ after 10, 20, 30 and 40 seconds of each drilling at (200, 400 and 800 RPM without liquid cooling) [1,9].

The dynamic analysis on the time axis (Fig. 7) demonstrated a flat tendency of the temperature to rise at 200 RPM drilling versus a steep rise of the temperature at 800RPM. Slow-drilling osteotomy is becoming more and more a method of choice for many implant dentists and the thermally conductive drills can allow the drilling of D1 bone without overheating it [1,9].

One of the drawbacks of *in-vitro* bone simulations is the missing blood circulation, as circulating blood may help to dissipate heat. According to Lee, et al. [13,14]. The insistence to the real 37°C, as the initial temperature of experiments, cannot be proven, however they showed evidence in two of their researches, that intraosseal temperature changes (ΔT) were similar, when initial temperatures were 26°C or 37°C [13,14].

Another subject of that study is the benefit of collecting healthy bone chips for bone graft and ridge augmentation. Using large diameters drills without irrigation eases bone chips collection, however over heated bone chips can cause inflammation and massive bone loss [7,9].

Conclusion

This study reveals the correlation between drilling speed and bone temperature elevation for high thermal-conductivity drills. There is a change in temperature elevation rate at high-speed drilling. In the high RPM (800) a faster temperature rise was observed towards the end of the drilling, compared the low RPM drilling (200) where the temperature remained constant during the entire drilling process. This study has demonstrated that using high thermal-conductivity drills at 200 RPM and 400RPM without liquid cooling even, in a very hard bone, such as a bovine rib, can be safe.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical Statement

The project did not meet the definition of human subject research under the purview of the IRB according to federal regulations and therefore was exempt.

Informed Consent Statement

Informed consent was obtained from all participants included in the study.

Authors' Contributions

All authors contributed equally to this paper.

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