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Effect of implant drill wear on heat generation at the marginal bone during implant site preparation using an infrared camera: An in vitro study

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Abstract

Background: The implant bed drilling not only leads to mechanical damage to the bone, but also increases the temperature of the bone close to the implant surface. The present study aimed to evaluate the effect of implant drill wear on heat generation during dental implant site preparation.

Methods: Four dental implant systems (Dio, MegaGen, Bio Horizons, and ITI) were selected for this study. Standard implant osteotomies were prepared in the bovine ribs (diameter, 4 mm; length, 10 mm) under similar conditions) speed, 800 rpm; torque, 40 Ncm). A total of 125 osteotomies were performed with each drill. Temperature changes in the drilling sequence of each system were measured using an infrared camera. Data were analyzed using analysis of variance (ANOVA) test in SPSS version 22.

Results: Significant changes in heat were observed in all four implant systems (Doi at T75, MegaGen at T100, Bio Horizons at T125, and ITI at T125) compared to the first drill use. Besides, comparison of temperature changes in different systems in each successive sequence of drill use showed no significant difference between the systems at T1, T25, and T50, whereas at T75, T100, and T125, there were significant differences in the heat produced by the four implant systems.

Conclusion: Multiple-use drills need to be diligently monitored. The ideal drill use before change was 75 times in the Doi system, 100 times in the MegaGen system, 125 times in the Bio Horizons system, and 125 times in the ITI system.

Keywords: Dental Implant, Heat generation, Infrared thermography, Osseointegration.

Introduction

Over the last two decades, the successful use of endosteal implants has increased due to improvements in implant materials and surfaces, besides advances in surgical procedures, implant supra-structures, and postoperative care[1]. Generally, osseointegration is defined as a direct, structural, and functional link between the living bone and the surface of a load-carrying implant[2]. The long-term clinical success of end osseous implants is highly dependent on osseointegration. It is known that the early failure of dental implants is associated with different implant-related, patient-related, and surgical (technique/environment) risk factors. Besides, thermally induced bone necrosis and fricative heat generated during surgery can lead to early implant failure[1].

Heat generation during drilling (rotary cutting) is one of the key factors influencing the failure of osseointegration. It is known that osseous tissue is highly sensitive to thermal damage[3]. During osteotomy, the crestal bone is generally more susceptible to marginal bone loss, which can be explained by the inadequate blood supply and the greater heat generated in the crestal bone, especially if the countersink drill is less effective in this area[4]. Moreover, implant bed drilling can cause significant mechanical damages to the bone and increase the temperature of the bone, directly adjoined to the implant surface.

Thermal trauma can influence the permanence of implants, as well as the maintenance of osseointegration[5]. The heat generated during the drilling process causes marginal bone loss and reduces the blood flow to the bone, leading to thermal osteonecrosis[6]. Heat generation in the bone induces alkaline phosphatase denaturation and bone devascularization and results in the loss of the periosteum[7]. It is known that temperatures above 70°C can cause immediate osteonecrosis. When the bone is exposed to a temperature of 55°C for 30 seconds and 47°C for 60 seconds, irreversible death of osteocytes is inevitable. A temperature of 47°C is defined as the thermal threshold for tissue damage[6]. Overall, the necrotic zone around the site of implant is directly proportional to the extent of heat generated.

The recurring use of drills can cause major wear at the cutting edge and increase the temperature, as well as the axial thrust force[8]. During osteotomy, mechanical energy is transformed to thermal energy. The total amount of heat depends on the geometry of the cutting edge, sharpness of the cutting tool, duration of the cutting process (continuous or intermittent), loading force, implant site preparation (multi-step and single-step), type of cooling system, rotary device speed, and bone density[9]. There are two well-known methods for the evaluation of real-time bone temperature changes during implant bed preparation: (1) thermocouple-based contact method (temperature measurement based on the heat transfer phenomenon known as conduction), and (2) non-contact thermometers, also known as infrared thermometers (measurement of the thermal field on a surface).

According to the literature, the two abovementioned methods have both advantages and disadvantages. Nevertheless, infrared thermometers have shown a shorter response time and higher sensitivity**.** In infrared thermometers with an input optics system, the beams are focused on a detector element that produces an electrical signal proportional to radiation[10]. The present study aimed to evaluate the effect of implant drill wear on heat generation during dental implant site preparation using an infrared camera.

Materials and Methods

In the present study, 50 fresh bovine rib segments (30 cm) were prepared and frozen after all soft tissue residues were removed. It has been proposed that the structure of the cortex and cancellous bone in the bovine rib is clinically similar to the human mandible[11]. Four dental implant systems were selected in this study: Dio UF (four-flute end drills; DIO Co., Busan, Korea); MegaGen Any One implant (a twisted drill, Korea); Bio Horizons tapered implant (a twisted drill; USA); and ITI bone level tapered implant (a twisted drill; BLT, Straumann, Switzerland). Standard implant osteotomy sites, with a length of 10 mm and a diameter suitable for placing an implant, with a standard diameter, were prepared (4 mm for Dio and MegaGen, 3.8 mm for Bio Horizons, and 4.1 mm for ITI)[12]. The drill diameter (in millimeters) and the sequence of drill use for each system were as follows:

System A (Dio): Starter → 2 mm → 2.7 mm → 3 mm → 3.2 mm.

System B (MegaGen): Starter → 2 mm → 2.5 mm → 2.8 mm → 3.3 mm → 3.6 mm.

System C (Bio Horizons): Starter → 2 mm → 2.5 mm → 3.2 mm.

System D (ITI): Starter → 2.2 mm → 2.8 mm → 3.5 mm.

Three identical sets of drills were evaluated for each implant drill system. The samples were stored at ambient temperature several times before the onset of the study. The specimens were then immersed in a water container; the sides were cut so that the lower half of the bone would be submerged in water. Next, the two ends of the bones, which were located on both sides of the water container, were attached to the legs by adhesive tape on both sides of the legs to prevent movements during the tests. The space between the bones and the edges of the container was then sealed using a silicone molding material (Figure 1).

Figure 1: In the present study, an infrared camera was used to record heat generation at the marginal bone during implant site preparation.

The bath temperature was held constant using a 300W heating element and a digital thermostat (SH-105DA, Shiraz, Iran) while conducting the tests at a mean temperature of 37±1°C[12]. According to the manufacturer's instructions, by using each drill set (including the starter drill and several consecutive drill sizes), the desired dimensions of the specimens were obtained. External irrigation at 40 mL/min with normal saline was used during drilling. In this study, a total of 125 osteotomies were created. After each use, the drills were washed and dried. All osteotomies were performed by the same clinician under the same conditions (speed, 800 rpm; torque, 40 Ncm), along with external irrigation using normal saline at room temperature to simulate a real-life clinical setting.

The heat generated at the marginal bone area (marginal cortical bone) was measured during the 1st, 25th, 50th, 75th, 100th, and 125th osteotomies for each system. The initial temperature (T0), which is the marginal bone temperature before drilling, and T_{max}, which is the maximum bone temperature at the end of drilling using the thickest drill, were recorded, and their difference ($\Delta t = T_{max} - T0$) was calculated for each system. The mean temperature difference was calculated for each system in different drilling times (1st, 25th, 50th, 75th, 100th, and 125th). An infrared thermal imaging camera (Testo 868, Germany) was used for all temperature measurements. The thermal camera marker was positioned at the drill entry site in the bone marginal area to show the bone temperature at a frequency of 9 Hz. For maximum spatial resolution, the camera was positioned 50 cm from the surface of the specimens and fixed with a silicone molding material.

To ensure accurate data recording during drilling, a video was captured by a camera and reviewed. The mean temperature difference (ΔT) was calculated for different drilling times (1st, 25th, 50th, 75th, 100th, and 125th). After collecting and entering the data into SPSS version 22, each drill system was evaluated based on ANOVA test. Next, using Tukey's post-hoc test, the systems were compared for each drill use. P-values less than 0.05 were considered statistically significant.

This study was approved by the Ethics Committee of Ahvaz Jundishapur University of Medical Sciences (Registration No.: IR.AJUMS.ABHC.REC.1397.047).

Results

The results of ANOVA test showed a significant difference in the amount of heat produced by all four implant drilling systems (Table 1 & Figure 2). Significant temperature changes were observed in the following sequences compared to the first drilling in the four implant systems: Dio at T75) P=0.026), MegaGen at T100 (P=0.034), Bio Horizons at T125 (P=0.047), and ITI at T125 (P=0.032). Moreover, by comparing temperature differences in each successive sequence for different systems, it was found that at T1, T25, and T50, there was no significant difference between different systems, whereas at T75, T100, and T125, there were significant differences in the heat produced by the four implant systems (Table 1).

Table 1. Comparison of the amount of heat generated by the studied implant systems.

Group	Sequence of drilling					
	1	25	50	75	100	125
DIO	1.83 ± 0.2	1.9 ± 0.2	2.53 ± 0.2	3.43 ± 0.38	3.97 ± 0.45	4.5 ± 0.1
Megagen	2 ± 0.36	2 ± 0.67	2.1 ± 0.26	2.27 ± 0.38	2.43 ± 0.46	3.07 ± 0.2
Bio Horizons	1.85 ± 0.07	1.9 ± 0.1	2.27 ± 0.38	2.47 ± 0.15	3.47 ±0.49	3.9 ± 0.36
ITI	2.17 ± 0.38	2.3 ± 0.3	2.43 ± 0.35	2.4 ± 0.1	2.63 ± 0.4	3.27 ± 0.32
Result	P = 0.367	P = 0.562	P = 0.388	P = 0.004*	P = 0.01*	P = 0.001*

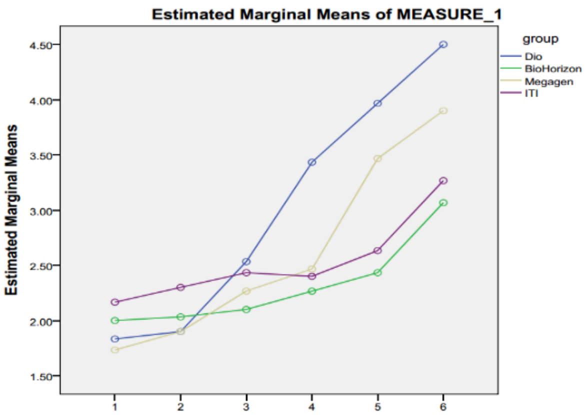

Figure 2: Comparison of the amount of heat generated by the implant system

A pairwise comparison showed a significant difference between the DIO system and the other three implant systems during the 75th use. The amount of heat produced by the DIO system was significantly higher than other systems. However, there was no significant difference in the amount of heat produced by other systems (Table 2).

Table 2. Pairwise comparison of the heat generated by four implant systems at T75.

Group	DIO	Megagen	Bio Horizons	ITI
DIO	__	P = 0.023	P = 0.004	P = 0.009
Megagen	P = 0.023	__	P = 0.588	P = 0.886
BIOHORIZONS	P = 0.004	P = 0.588	__	P = 0.936
ITI	P = 0.009	P = 0.886	P = 0.936	__

A pairwise comparison showed a significant difference between the DIO system and the other two systems (Bio Horizons and ITI) in the 100th drill use. The heat produced by the DIO system was significantly higher than that of the Bio Horizons and ITI systems; however, no significant difference was found between the other systems (Table 3).

Table 3. Pairwise comparison of the heat generated by four implant systems at T100.

Group	DIO	Megagen	Bio Horizons	ITI
DIO	__	P = 0.56	P = 0.014	P = 0.029
Megagen	P = 0.56	__	P = 0.09	P = 0.19
BIOHORIZONS	P = 0.014	P = 0.09	__	P = 0.947
ITI	P = 0.029	P = 0.19	P = 0.947	__

A pairwise comparison showed a significant difference between the DIO system and the other two systems (Bio Horizons and ITI) in the 125th use. The heat produced by the DIO system was significantly higher than that of the Bio Horizons and ITI systems; however, no significant difference was observed between the other systems in the 125th use (Table 4).

Table 4. Pairwise comparison of the heat generated by four implant systems at T125

Group	DIO	Megagen	Bio Horizons	ITI
DIO	__	P = 0.095	P = 0.001	P = 0.002
Megagen	P = 0.095	__	P = 0.021	P = 0.077
BIOHORIZONS	P = 0.001	P = 0.021	__	P = 0.798
ITI	P = 0.002	P = 0.077	P = 0.798	__

Discussion

Four dental implant systems (DIO, MegaGen, Bio Horizons, and ITI) were used in the present study. These systems were selected as they are widely recognized around the world and are available and commonly used in many specialized dental offices. Various studies have examined the bone heat generation during drilling, and different bone types have been studied, including the rabbit mandible, pig maxilla and mandibles, cortical/medullary bovine bone block, polymeric material, porcine ribs, and bovine cortical bone[13]. Besides, it has been reported that an increase in bone density can cause a temperature rise[14]. In this study, the bovine back rib bones were used due to their close similarity to the human mandible. It is known that the bovine back rib bone and the human mandible have the same density, as well as cortical and medullary ratios. Moreover, bovine back ribs are readily available[15].

In this study, to minimize discrepancies in bone density or cortical thickness, all bone samples were obtained from one animal[16]. Moreover, all parameters that could affect the thermophysical properties of materials and consequently, heat distribution were excluded. After preparing fresh bovine ribs, the specimens were frozen to assess the mechanical and thermophysical properties. Sedlin and Hirsch (1966) suggested that freezing a specimen before testing (up to four weeks) caused no significant change in the bone physical properties[17]. The specimens, before being subjected to osteotomy, were maintained at 37°C in a water bath (similar to the human body temperature)[18]. Half of the samples was kept out of water. The ambient temperature during the experiments was between 20°C and 23°C.

After the initial preparation phase, the initial temperature (T0) of the samples was found to vary considerably (range, 26-31°C); therefore, temperature variations (ΔT) induced by drilling were compared in this study, not the peak temperatures. This decision was made based on the first law of thermodynamics, which states that variations in the internal energy of a thermodynamic system correspond to the total amount of heat and work entering the system. Therefore, the quantity of heat absorbed by the sample, as well as the consequent increase in temperature, is independent of the initial temperature (T0) of the sample[13]. In this regard, Chacon et al. (2006) found that the initial temperature of the samples remained constant (37°C) at a depth of 15 mm[12]. However, the results of a study by Luc Chiari et al. (2014) revealed that the initial temperature was variable; in their study, ΔT was also measured for data analysis[13].

In the present study, an infrared camera was used to record bone heating during osteotomy. This method has several advantages over other methods described in the literature. It is well-known that an infrared camera is more accurate than a thermocouple and easier to use. According to the manufacturer's instructions, the characteristics of the infrared camera used in the present study were as follows: accuracy, 0.2%, IR resolution of 160×120 pixels; and temperature measurement range, -30°C to +650°C.

On the other hand, the position of the thermocouple may not be precise enough, and positional inaccuracy may affect temperature measurements. Besides, the temperature measured by thermocouples is dependent on the bone quantity and quality at the implant site, as well as the thermocouple[19]. Likewise, an infrared camera provides accurate temperature measurements without contact with the bone and also eliminates the need for a separate probe mounted at the preparation site; besides, the heat measurements are instantaneous[13].

In this study, osteotomy was performed at 800 rpm. According to previous studies on drilling speed, there is no specific safe speed range for a clinician to follow. The drilling speed cannot be considered an independent factor in heat generation during osteotomy, and it needs to be evaluated along with other variables, including applied force[13]. In some studies, osteotomy was performed at a constant force above 1.2 kg. Nevertheless, there are some studies that have not been conducted under constant pressure[20, 21, 22]. In the present study, the force amplitude of each step was not constant. Therefore, to maximize shear capacity and reduce heat production, the clinician adjusted the load force according to the perceived resistance, with the drill spinning on its axis.

In this study, to examine heat generation and drill wear during dental implant site preparation, direct factors which have significant effects on the drilling behavior were assessed. No attempt was made to simulate the sterilization process at the clinic (drills were only cleaned with distilled water). Therefore, sterilization does not predict the positive or negative effects on long-term drilling efficiency. In this regard, Jochum and Reichart (2000) suggested that Cannon drills, after disinfection and autoclaving, showed trivial cutting-edge wear after 51 uses (1.34-1.36 µm increase in the width of cutting edge per 10 osteotomies). However, the heat generated by disinfected and sterilized drills was below 47°C, which showed no significant difference with drills that were only cleaned with distilled water[23].

In the present study, the number of active drilling was directly associated with heat generation; in other words, as the number of drills increased, the heat generation increased, as well. A significant difference was observed in heat generation between the studied implant systems as compared to the initial drilling (Dio=T75, MegaGen=T100, Bio Horizons=T125, and ITI=T125). Overall, the repeated use of Dio drills (75 uses) caused drill wear and consequently, increased the heat generation. Heat generation and drill wear during dental implant site preparation in MegaGen, Bio Horizons, and ITI systems were observed after 100, 125, and 125 uses, respectively.

Likewise, by comparing the temperature differences in each successive sequence of implant use, it was found that at T1, T25, and T50, there was no significant difference between different systems, while at T75, a significant difference was found between the Dio system and the other three implant systems. No significant difference was found between the Dio and MegaGen systems at T100, while Bio Horizons and ITI systems showed significant differences at T100. It is important to note that multi-step drilling sequences remove different amounts of bone, depending on the size and number of drills during osteotomy. The number of cutting drills in the four systems varied in the present study: DIO, four drills; MegaGen, five drills; Bio Horizons, three drills; and ITI, three drills.

A decline in the number of drills in the drill use sequence is associated with a larger extent of excavated bone in each step and contributes to increased heat. Therefore, it can be explained why the MegaGen system generated the lowest heat at T1, while the three-drill system showed greater heat generation at T1. However, the durability of a drill for long periods of use depends on the drill specifications (drill material, drill diameter, cutting face, helix angle, and drill point) and geometric features.

In this study, drill wear occurred earlier in the Dio system (T75); nevertheless, it should be noted that the implant kits are system-specific; for example, the Dio system includes drills of various lengths with diameters corresponding to those of the planned implant. Different lengths of the dental implant are commonly used for primary implant stability. If the surgical kit is used properly, drill wear may not occur earlier than other implant systems, and the efficiency of drills may be increased. This issue can be addressed by analyzing the number and length of implants used in different treatment centers in other studies. Finally, in the present study, thermal variations during drilling (when change was perceptible) were observed between 3.06°C and 3.46°C. If this temperature is added to the normal body temperature (37°C), the temperature increment still remains below the osteonecrosis threshold of 47°C.

In conclusion, drills can be used without any concerns up to a certain number of times. However, it should be noted that several factors are involved in generating heat, such as the drill geometry, cutting tool sharpness, applied pressure, cutting duration (continuous or intermittent), multi- or single-stage systems, cooling systems, rotary device speed, and bone density. Overall, the rates of drill use and drill wear are among several factors that influence heat generation. Therefore, maximum effort should be made to reduce trauma and heat generation by dental implant drills during osteotomy.

Conclusion

The relationship between heat generation and drilling wear during osteotomy was multi-factorial, and its complexity varied in different systems, which should be addressed in clinical practice. Multiple-use drills must be diligently monitored and changed repeatedly, especially when temperature during drilling is increased. The ideal number of drill use until drill change was 75 times in the Dio system (T75), 100 times in the MegaGen system (T100), 125 times in the Bio Horizons system (T125), and 125 times in the ITI system (T125).

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Authors' Contributions

E.G., performed the study. E.G., conducted the literature review. E.G., and M.N performed the experiments and drafted the manuscript. E.G., performed the experimental procedures. M.N. conducted statistical analyses and interpretation of data. All authors critically revised the manuscript for intellectual content. All authors read and approved the final manuscript.

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Competing Interests

The authors declare no competing interests in relation to the authorship and/or publication of this article.

Ethics Approval and Consent to Participate

The study protocol was approved by the Ethics Committee of Ahvaz Jundishapur University of Medical Sciences.

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