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ORIGINAL ARTICLE

Influence of bone density, drill diameter, drilling speed, and irrigation on temperature changes during implant osteotomies: an in vitro study

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Abstract

Objective The aim of this in vitro study was to evaluate the influence of bone type, drill diameter, drilling speed, and irrigation on heat generation while performing osteotomy for dental implants.

Materials and methods Six polyurethane foam blocks simulating type I (dense) and type IV (soft) bone were selected for the study. Each block was subjected to two different experimental conditions for each drill (2- and 3.5-mm diameter): three subgroups were created: (a) revolutions per minute (50, 100, or 800 rpm) and (b) irrigation (with or without irrigation).

Results In 2-mm drill group, maximum temperature attained was practically identical: 23.73 ± 2.28 °C in the cortical bone and 23.74 ± 2.03 °C in the cancellous bone. For 3.5-mm, groups showed similar results (25.01 ± 1.88 °C for cortical and 24.05 ± 1.94 °C for trabecular bone). In any type of bone, the presence of irrigating fluid helped to control the maximum temperature ($p = 0.001$). When comparing the 2-mm and 3.5-mm drills, most differences were found at 100 rpm without irrigation ($p < 0.001$) and at 800 rpm with irrigation ($p = 0.001$).

Conclusions Maximum temperature attained was always below the critical threshold that can cause osteonecrosis, showing that both external irrigation with higher drilling speeds and no irrigation with lower speeds were effective methods to avoid excessive heat generation.

Clinical relevance Despite being always below the critical temperature, bone type, drill diameter, drilling speed, and irrigation must be considered temperature-influencing factors during implant osteotomies.

Keywords Dental implant · Implant drill · In vitro · Bone mineral density · Polyurethane foam

Introduction

Osseointegration is the direct contact between the bone and the surface of an implant without an intervening fibrous layer [1]. As the bone has low thermal conductivity, during preparation of the implant site, attrition of the burs can cause overheating and, consequently, bone necrosis [2]. This could result in interposition of fibrous tissue at the implant-bone interface, influencing the process of osseointegration, favoring bone loss, and diminishing implant survival rate [3, 4]. Hence, an atraumatic surgical technique and initial stability of the implant [5–7], which are directly related to the preparation of the implant site [1], are required to avoid this phenomenon. The bone structure determines the reaction against increase in temperature. Medullary bone, due to its greater vascularization, has better capacity to dissipate heat, whereas higher temperatures could be attained while drilling in dense cortical bone owing to the higher bone density and reduced capacity for heat dissipation [8, 9]. The temperature should be maintained under 47 °C during preparation of the implant site, and the drilling time should be less than 1 min [10, 11].

Several factors may affect temperature variations during the preparation of the implant site, such as the drilling depth [12], drill design and material [13–18], drill sharpness [19,

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20], drilling speed and pressure [21–23], bone density and irrigation [24–26], and number of uses and sterilization processes [27].

In external irrigation, the coolant contacts the sides of the bur while drilling. By contrast, in internal irrigation, the coolant flows internally through the hand-piece and drill, allowing direct contact of the coolant with the internal working area. A combination of both internal and external systems has also been tested and described in the literature as a factor influencing thermal changes [28]. Apparently, the greater the depth of drilling, the greater would be the heat generated, as the coolant does not reach the deepest area of the prepared site [29]. However, there is a lack of literature analyzing the definite relationship between the generation of heat and depth of the osteotomy.

Many devices and techniques have been described to physically measure the amount of heat generated during preparation of the implant site. Infrared thermography is an indirect method used to measure temperature by detecting changes in the surface through a scale color [30, 31]. Another device is the thermocouple; if it is placed adequately close to the working area, it can detect the difference in electric potential between two metals, being an extremely sensitive detector of thermal changes [22, 26].

Therefore, the aim of this in vitro study was to evaluate the influence of bone type, drill diameter, drilling speed, and irrigation system on heat generation while performing osteotomy for dental implants.

Materials and methods

Study design

This study was performed on biomedical test blocks resembling human bone (Sawbones®, Pacific Research Laboratories, WA, USA). These blocks are manufactured from solid and rigid polyurethane foam simulating type I (dense) and type IV (soft) bone, according to the Misch's bone density classification [32]. The foam density is 0.08 g/cm^3 for density 1 (D4) and 0.48 g/cm^3 for density 4 (D1), with a compressive strength of 0.6 MPa for D4 and 18 MPa for D1, and a compressive modulus of 16 MPa for D1 and 445 MPa for D4. The initial block dimensions were 130 × 180 × 20 mm. Thereafter, the blocks were sectioned into smaller samples with dimensions of 130 × 16 × 10 mm. Six blocks were selected for the study (3 D1 blocks and 3 D4 blocks). Each block received 12 osteotomies on each side, resulting in a total of 288 osteotomies. The first osteotomy was performed with a 2-mm diameter drill (2-mm phase; $n = 144$). Later, a 3.5-mm diameter drill was used in the same preparation (3.5-mm phase; $n = 144$). The osteotomies were performed 5 mm apart to not influence the temperature measurements of the surrounding osteotomies. This in vitro study was approved by the ethical research committee of the Universitat Internacional de Catalunya (CIR-ELM-2017-02).

The blocks were divided into two primary groups according to bone density (cortical and trabecular bone), and each block was subjected to two different experimental conditions for each drill (2- and 3.5-mm diameter): (a) revolutions per minute (50, 100, or 800 rpm) and (b) irrigation (with or without irrigation), resulting in three subgroups per primary group: (1) subgroup 1: 50 rpm and no irrigation; (2) subgroup 2: 100 rpm and no irrigation; and (3) subgroup 3: 800 rpm with irrigation. Figure 1 shows the flowchart of group distribution.

Drilling procedure

A special machine with an attached implant motor designed to produce continuous drilling motion was used for the study. The device was coupled to a 20:1 reduction-speed hand-piece with a predetermined load of 2 kg (SurgicPro, NSK Nakanishi INC. Japan). A thermometer with an accuracy of 0.1 °C and two thermocouples (DEM 106, Velleman®, Belgium) were added to each block to register the maximum temperature attained while performing the osteotomies (Fig. 2).

Twenty-four new drills from Straumann® (Straumann®, AG, Waldenburg, Switzerland) were used in this study: 12 2.0-mm diameter pilot drills and 12 3.5-mm diameter helical drills. Each drill was used only for one block side to avoid the bias of drill wear. According to the study group distribution, if saline irrigation was used (Braun, GmbH, Germany), it flowed continually at a speed of 50 ml/min and at 21 °C (room temperature). The temperature of the saline solution was evaluated every 5 min, and another saline source was added in case of temperature increase of 1 °C.

Data retrieval

Two type K thermocouples and a digital thermometer with an accuracy of 0.1 °C were inserted into two holes placed at each side of an osteotomy, 1 mm lateral to the osteotomy level and at 5 mm depth. The primary variable of the investigation was the maximum temperature attained during each preparation, which was recorded at two locations (buccal and lingual) in degrees Centigrade. The data were entered in a Microsoft Excel Office®2011 spreadsheet (Microsoft Corporation, Redmond, USA). Sufficient waiting time, following each osteotomy before the next drilling sequence, was allowed to elapse until the temperature returned to baseline level (21 °C).

Statistical analyses

Statistical analyses were performed using the Statgraphics®Plus 5.1 software (Statpoint Technologies, INC Virginia, USA). The descriptive analysis of all variables

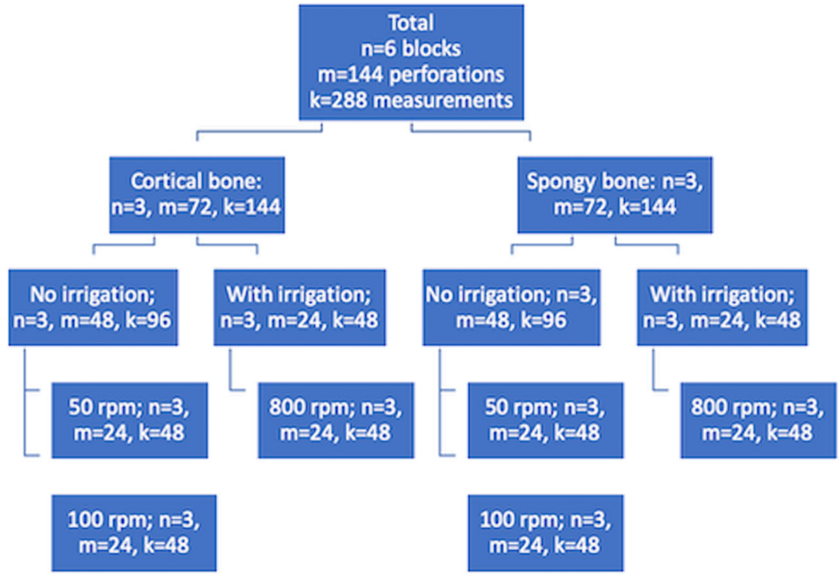

Fig. 1 Flowchart showing the number of blocks (n), number of osteotomies (m), and number of temperature measurements (k)

included calculations of mean, standard deviation, minimum, maximum, and median. The Kolmogorov-Smirnov test rejected the adjustment of the temperature variable to normality; however, the large sample size allowed a parametric approach for achieving normality.

Regarding the inferential analysis, linear models of generalized estimation equations were used because of the hierarchical design of observations: 2 measurements per perforation and 24 perforations per block and drill. The dependent variable was always the maximum temperature attained, and the mean was compared for different levels of independent factors. In the first model, the effect of bone type was evaluated, and thereafter, speed and irrigation factors were incorporated into the model, estimating all the principal effects and interaction. The Wald Chi-squared statistic determined the significance of the factors. Multiple comparisons were corrected using the Bonferroni criteria. The level of significance used in the analyses was 5% ($\alpha = 0.05$).

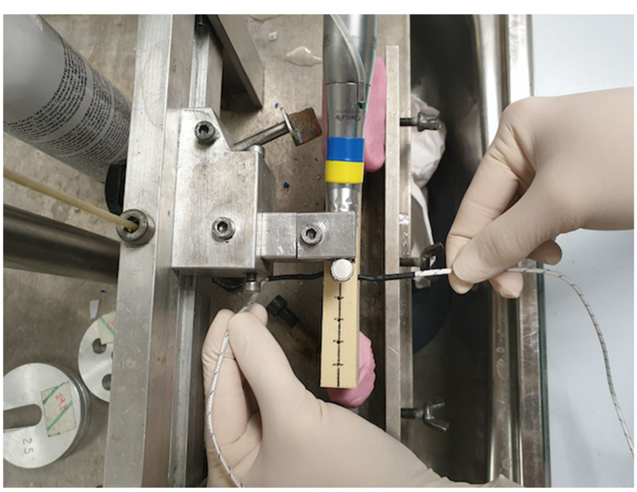

Fig. 2 Specially designed device for measuring changes in temperature during implant osteotomies

Results

Two-millimeter drills

Effect of bone type

The average maximum temperature attained was practically identical in both block groups: 23.73 ± 2.28 °C in the cortical bone and 23.74 ± 2.03 °C in the cancellous bone ($p > 0.05$). Depending on bone density, means were slightly higher than medians, suggesting that possible extreme cases had limited influence in such large sample sizes on the general average (Table 1).

Effect of speed and irrigation

In any type of bone, the presence of irrigating fluid controlled the maximum temperature better than its absence. The average maximum temperature attained depended specifically on the used speed–irrigation combination and the type of bone where osteotomy was performed ($p = 0.001$). In the cortical bone, no considerable differences in temperature between working at 50 or 100 rpm without irrigation were evident. Compared to the cortical bone, the temperature was significantly lower while working at lower speeds without cooling (100 rpm) in the trabecular bone ($p = 0.001$). At 800 rpm, bone density did not affect thermal changes during implant osteotomy ($p > 0.05$) (Fig. 3).

Table 1 Mean, standard deviation, minimum, maximum, and median maximum temperature in degrees centigrade according to type of bone during implant osteotomies with 2-mm drills

	N	Mean	Standard deviation	Minimum	Maximum	Median
Cortical	144	23.73	2.28	20.20	33.00	23.40
Trabecular	144	23.74	2.03	19.80	27.20	23.30
Total	288	23.74	2.16	19.80	33.00	23.30

Drills of 3.5 mm

Effect of bone type

The mean maximum temperature was 0.96 °C higher in the trabecular-bone block than that in the cortical-bone block (25.01 ± 1.88 °C and 24.05 ± 1.94 °C, respectively), although the difference was not statistically significant ($p > 0.05$) (Table 2).

Effect of speed and irrigation

Similar to the 2-mm drill, the presence of irrigating fluid controlled the maximum temperature better than its absence, in blocks of both densities. In the cortical bone, the temperature was significantly higher while working at higher speeds (100 rpm) ($p = 0.02$) compared to that while working at lower speeds (50 rpm). In the cancellous bone, no significant difference in temperature between working at 50 or 100 rpm ($p < 0.05$) was evident (Fig. 4).

The model showed that the average maximum temperature attained depended specifically on the speed–irrigation combination and type of bone. In the cortical bone, the temperature at 100 rpm was higher than that at 50 rpm. By contrast, in the trabecular bone, both temperatures were approximately equal, elucidating the influence of bone density. The reciprocal interpretation is as follows:

– At 50 rpm without irrigation, cortical bone temperature was significantly lower than trabecular bone temperature ($p < 0.001$).
– At 100 rpm without irrigation, cortical bone temperature was significantly higher than trabecular bone temperature ($p = 0.005$).
– At 800 rpm with irrigation, no statistically significant differences were found ($p > 0.05$).

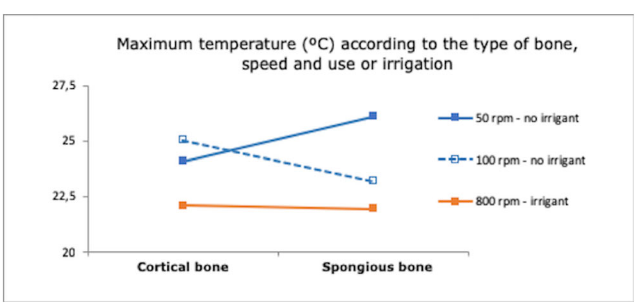

Fig. 3 Two-millimeter drills: maximum temperatures according to type of bone, drilling speed, and irrigation

Comparative evaluation between 2- and 3.5-mm drills

The temperature changes with the 2-mm diameter drills (phase 1) and 3.5-mm diameter drills (phase 2) are as follows:

The mean maximum temperature attained was similar in different types of irrigation, speed, and bone. When comparing the 2-mm and 3.5-mm drills, most statistically significant differences were found during implant osteotomy in trabecular bone, at 100 rpm without irrigation ($p < 0.001$) and at 800 rpm with irrigation ($p = 0.001$) (Table 3).

Discussion

Studies have shown that bone temperature should be maintained at 47 °C during preparation of the implant site to avoid bone necrosis [10], and several factors affecting temperature changes during implant site preparation, such as drill design and geometry [13], drilling speed and pressure [21–23], irrigation and bone density [24–26], should be considered prior to implant osteotomies. This study revealed the variable influences of drill diameter, drilling speed, bone density, and irrigation on heat generation during the preparation of implant sites in artificial bone blocks. Artificial bone blocks made from polyurethane were selected considering that their mechanical properties are comparable to those of human cancellous and cortical bone, according to the American Society for Testing [33]. By contrast, other studies have used animal bone such as bovine or porcine ribs and obtained reliable results [17–19]. However, these animal samples might have discrepancies in relation to size and/or percentage of trabecular and cortical bone.

Although the use of thermocouples, which digitally measure temperature changes, is still under discussion [3], their values are influenced by the material of the sensor, probe isolation, and/or recording depth. In this

Table 2 Mean, standard deviation, minimum, maximum, and median maximum temperature in degrees centigrade (°C) according to type of bone during implant osteotomies with 3.5-mm drills

	N	Mean	Standard deviation	Minimum	Maximum	Median
Cortical	144	24.05	1.94	19.70	28.80	24.30
Trabecular	144	25.01	1.88	20.30	28.20	25.90
Total	288	24.53	1.97	19.70	28.80	25.00

study, two type K thermocouples were used instead of one to enhance the accuracy of temperature measurements and were located adequately close to the working area, while maintaining the minimum secure distance to prevent any damage to the devices while drilling; however, the advantage of one vs. two thermocouples still remains unclear. Maintaining an accurate distance between the probes of the thermocouple and heat source is necessary to obtain a reliable and precise temperature record. Increasing this distance from 0.3 to 0.7 mm from the edge of the osteotomies has shown a decrease of 2 °C [20]. Accordingly, in this study, the thermocouples were positioned 0.4 mm from the osteotomies. For the 3.5-mm osteotomies, the position of the thermocouples was altered to allow the same distance of 0.4 mm.

Regarding the force applied during preparation of the implant site, majority of the previous in vitro studies have applied constant loads by pneumatic systems or by applying weights [28]. A 2-kg load exerting limited pressure to avoid generation of excessive heat was selected, as recommended by Tehemar [3]. However, continuous drilling protocol was used, which does not correspond to the actual clinical protocol, and though the technique used was standardized, it could have influenced the maximum temperature attained.

As the bone-drill interface is quite small, saline irrigation can prevent overheating [3]. Drilling should be intermittent, allowing saline to access the entire length of the osteotomy. Additionally, this will permit the removal of bone chips, maintaining the cutting efficiency of the drills [26, 31]. However, in this study, as the osteotomies were performed with a calibrated load of 2 kg, continuous drilling was performed until the preparation was complete.

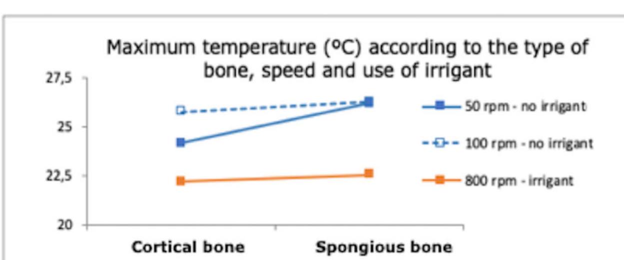

Fig. 4 Drills of 3.5-mm: maximum temperatures according to type of bone, drilling speed, and irrigation

The results of this study showed that differences in bone density are one of the principal factors leading to temperature changes. While using the 2-mm diameter drills, the two types of bone showed no differences in the maximum temperature attained. However, if the effects of irrigation and drilling speed are considered, various conclusions can be drawn. Use of a coolant provided better control of the maximum temperature attained. Use of a coolant with higher speeds (800 rpm) ensured better temperature control because of heat dissipation by the coolant, although without statistically significant differences. The relationship between drilling speed and irrigation was also analyzed. Use of irrigation also ensured attainment of lower maximum temperatures under high speeds. In the cortical bone, higher temperatures were attained at 100 rpm than those at 50 rpm; however, in the trabecular bone, temperatures at the two speeds were equal.

Critical evaluation of the results of our study shows the following limitations. First, the temperatures were evaluated at a single depth of 10 mm; no comparisons with superficial or deeper depths were performed, which could have led to different results. Second, the drills were not sterilized between the osteotomies, and the debris of bone blocks was cleaned with saline solution. Some authors have shown that autoclaving can reduce the cutting efficiency of drills, which might influence the heat generation during drilling [20].

Conclusions

In this study, the maximum temperature attained was always below the critical threshold that can cause osteonecrosis

Table 3 Results of the Wald Chi-squared statistic of the linear model of generalized estimation equations

	p value
Cortical bone–50 rpm–no irrigant	0.703
Cortical bone–100 rpm–no irrigant	0.051
Cortical bone–800 rpm–with irrigant	0.678
Trabecular bone–50 rpm–no irrigant	0.482
Trabecular bone–100 rpm–no irrigant	< 0.001*
Trabecular bone–800 rpm–with irrigant	0.001*

*Values showing statistical significant differences ($p < 0.05$)

showing that both external irrigation with higher drilling speeds and no irrigation with lower speeds were effective methods to avoid excessive heat generation. However, optimum drilling parameters must be selected for routine clinical practice to avoid or minimize the possibility of bone necrosis. Use of irrigation with high speeds demonstrated better control of the maximum temperature. However, the results of the study should be interpreted with caution due to the in vitro nature of this study and its inherent limitations.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

References

1. Schroeder A, Van Der Zypen E, Stich H, Sutter F (1981) The reaction of bone, connective tissue and epithelium to endosteal implants with sprayed titanium surfaces. J Maxillofac Surg 9:15–25
2. Carvalho AC, Queiroz TP, Okamoto R, Margonar R, Garcia IR Jr, Magro Filho O (2011) Evaluation of bone heating, immediate bone cell viability, and wear of high-resistance drills after the creation of implant osteotomies in rabbit tibias. Int J Oral Maxillofac Implants 26:1193–1201
3. Tehemar SH (1999) Factors affecting heat generation during implant site preparation: a review of biologic observations and future considerations. Int J Oral Maxillofac Implants 14:127–136
4. Möhlhenrich SC, Modabber A, Steiner T, Mitchell DA, Hölzle F (2015) Heat generation and drill wear during dental implant site preparation: systematic review. Br J Oral Maxillofac Surg 53: 679–689
5. Van Staden RC, Guan H, Johnson NW, Loo YC, Meredith N (2008) Step-wise analysis of the dental implant insertion process using the finite element technique. Clin Oral Implants Res 3:303–313
6. Albrektsson T, Albrektsson B (1978) Microcirculation in grafted bone. A chamber technique for vital microscopy of rabbit bone transplant. Acta Orthop Scand 49:1–7
7. Almeida KP, Delgado-Ruiz R, Carneiro LG, Leiva AB, Calvo-Guirado JL, Gómez-Moreno G, Malmström H, Romanos GE (2016) Influence of drilling speed on stability of tapered dental implants: an ex vivo experimental study. Int J Oral Maxillofac Implants 31(4):795–798
8. Leunig M, Hertel R (1996) Thermal necrosis after tibial reaming for intramedullary nail fixation. A report of three cases. J Bone Joint Surg Br 78:584–587
9. Gehrke SA, Bettach R, Taschieri S, Boukhris G, Corbella S, Del Fabbro M (2015) Temperature changes in cortical bone after implant site preparation using a single bur versus multiple drilling steps: an in vitro investigation. Clin Implant Dent Relat Res 17: 700–707
10. Eriksson AR, Albrektsson T (1983) Temperature threshold levels for heat-induced bone tissue injury: a vital microscopic study in the rabbit. J Prosthet Dent 50:101–107
11. Eriksson RA, Adell R (1986) Temperatures during drilling for the placement of implants using the osseointegration technique. J Oral Maxillofac Surg 44:4–7
12. Gehrke SA, Aramburu JS (2016) The influence of drill length and irrigation system on heat production during osteotomy preparation for dental implants: an ex vivo study. Clin Oral Implants Res 0:1–7
13. Pirjamalineisiani A, Jamshidi N, Sarafbidabad M, Soltani N (2015) Assessment of experimental thermal, numerical, and mandibular drilling factors in implantology. Brit J Oral Max Surg 54:400–404
14. Cordioli G, Majzoub Z (1997) Heat generation during implant site preparation: an in vitro study. Int J Oral Maxillofac Implants 12: 186–193
15. Oh HJ, Wikesjö UM, Kang HS, Ku Y, Eom TG, Koo KT (2011) Effect of implant drill characteristics on heat generation in osteotomy sites: a pilot study. Clin Oral Implants Res 22:722–726
16. Karaca F, Aksakal B (2013) Effects of various drilling parameters on bone during implantology: an in vitro experimental study. Acta Bioeng Biomech 15:25–32
17. Oliveira N, Alaejos-Algarra F, Mareque-Bueno J, Ferrés-Padró E, Hernández-Alfaro F (2012) Thermal changes and drill wear in bovine bone during implant site preparation. A comparative in vitro study: twisted stainless steel and ceramic drills. Clin Oral Implants Res 23:963–969
18. Sumer M, Misir AF, Telcioglu NT, Guler AU, Yenisey M (2011) Comparison of heat generation during implant drilling using stainless steel and ceramic drills. J Oral Maxillofac Surg 69:1350–1354
19. Ercoli C, Funkenbusch PD, Lee HJ, Moss ME, Graser GN (2004) The influence of drill wear on cutting efficiency and heat production during osteotomy preparation for dental implants: a study of drill durability. Int J Oral Maxillofac Implants 19:335–349
20. Jochum RM, Reichart PA (2000) Influence of multiple use of timedur-titanium cannon drills: termal response and scanning electron microscopic findings. Clin Oral Implants Res 11:139–143
21. Reingewirtz Y, Szmukler-Moncler S, Senger B (1997) Influence of different parameters on bone heating and drilling time in implantology. Clin Oral Implants Res 8:189–197
22. Sharawy M, Misch CE, Weller N, Tehemar S (2002) Heat generation during implant drilling: the significance of motor speed. J Oral Maxillofac Surg 60:1160–1169
23. Kondo S, Okada Y, Iseki H, Hori T, Takakura K, Kobayashi A, Nagata H (2000) Thermological study of drilling bone tissue with a high- speed drill. Neurosurgery 46:1162–1168
24. Eriksson RA, Albrektsson T, Albrektsson B (1984) Heat caused by drilling cortical bone. Temperature measured in vivo in patients and animals. Acta Orthop Scand 55:629–631
25. Delgado-Ruiz RA, Sacks D, Palermo A, Calvo-Guirado JL, Perez-Albacete C, Romanos GE (2016) Temperature and time variations during osteotomies performed with different piezosurgical devices: an in vitro study. Clin Oral Implants Res 27:1137–1143
26. Gehrke SA, Loffredo Neto H, Mardegan FE (2013) Investigation of the effect of movement and irrigation on temperature in the drilling of cortical bone. Br J Oral Maxillofac Surg 51:953–957
27. Chacon GE, Bower DL, Larsen PE, McGlumphy EA, Beck FM (2006) Heat production by 3 implant drill systems after repeated drilling and sterilization. J Oral Maxillofac Surg 64:265–269
28. Benington IC, Biagioni PA, Briggs J, Sheridan S, Lamey PJ (2002) Thermal changes observed at implant sites during internal and external irrigation. Clin Oral Implants Res 13:293–297
29. Sener BC, Dergin G, Gursoy B, Kelesoglu E, Slih I (2009) Effects of irrigation temperature on heat control in vitro at different drilling depths. Clin Oral Implants Res 20:294–298
30. Scarano A, Lorusso F, Noumbissi S (2020) Infrared thermographic evaluation of temperature modifications induced during implant site

preparation with steel vs. zirconia implant drill. J Clin Med 9:148–158

31. Laurito D, Lamazza L, Garreffa G, De Biase A (2010) An alternative method to record rising temperatures during implant site preparation: a preliminary study using bovine bone. Ann Ist Super Sanita 46:405–410
32. Misch CE, Degidi M (2003) Five-year prospective study of immediate/early loading of fixed prostheses in completely edentulous jaws with a bone quality-based implant system. Clin Implant Dent Relat Res 5:17–28
33. ASTM F1839–08 (2016) Standard specification for rigid polyurethane foam for use as a standard material for testing orthopaedic devices and instruments. ASTM International West Conshohocken. PA. www.astm.org. Accessed Sept 2019