Analysis of the temperature variations in different implant systems with thermal imaging camera: An *in vitro* study on bovine ribs

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ABSTRACT

Aim The aim of this study was to evaluate the thermal variations during implant osteotomy with three different implant systems at different drilling speeds in the bovine bone. Also, we aimed to explore the period over 47°C during drilling with each drill of each implant system.

Materials and methods Using bovine ribs, 3 implant systems were compared: Implantium® (Dentium, Seoul, Korea), Straumann® (Institut Straumann AG, Basel, Switzerland), and Anyridge® (Anyridge, Seoul, Korea). With increasing diameter drills (Implantium (4 drills); Straumann (4 drills); Anyridge (5 drills)) at three drilling speeds (150, 250, and 400 rpm) implant bed preparations were performed with a conventional approach. Maximum heat generated and the duration of the generated heat over 47°C in each drill of each implant system at different drilling speeds were measured, and results were compared.

Results Significant increase in temperature was observed for the majority of the drills at 250 rpm (except D-I2, S-4.2, M-2) and 400 rpm (except M-2) when compared to the 150 rpm ($p<0.05$). However, between 250 and 400 rpm temperature variations did not follow a uniform trend and showed differences based on the drill used. Maximum generated heat observed in D-I2 (400rpm) as 59.37°C for Implantium system, in S-3.5 (250 rpm) as 58.71°C for Straumann system, in M-2.8 (400rpm) as 75.67°C Anyridge system. For all measurements Implantium and Strauman systems exhibit lower variations in temperature when compared to the Anyridge system. The period over critical threshold also below the limit of 1 minute for all measurements. The maximum duration of over 47°C was observed for the drill M-2.8 (400rpm) as 15.63 seconds.

Conclusion It can be concluded based on the results of the study that when considering the temperature increase and the time spent for preparation of implant site over the critical threshold by the evaluated systems at different speeds without irrigation was in safe limit clinically. Further in vitro and in vivo studies by considering more parameters required to be conducted to determine the optimum drilling parameters for each implant system in clinical practice.

INTRODUCTION

Dental implants have become a reliable treatment option to restore functional and esthetic deficiencies which occur after tooth loss, and the demand for dental implants still continues to be increasing markedly along with the developments in the biomedical era (1). The success rates of implant treatment have been reported to be over 90 % and the postoperative bone healing is considered as the sine qua non of long term success of dental implants (2, 3). Various implant, patient and operator related factors affect the success of dental implants. One of the most common factors is thermal damage during implant osteotomy has significant importance because the cells of bone tissue are susceptible to a thermal injury (4, 5). Excessive increase in temperature affects the tissue regenerative capacity and mechanical properties in a negative way that results in early implant failure (6-8). Thermally induced necrosis during implant bed preparation demonstrated associated with temperature and exposure time. Increase of the temperature above 56°C during implant bed preparation could lead alkaline phosphatase to be rapidly denaturized and result in permanent damage (9-11). Also, blood flow reduces as a result of an increase in temperature and affect the health of the adjacent tissues (12). Eriksson and Albrektsson et al. (13) reported the critical threshold for tissue survival is 47°C for more than 1 min. Several parameters influence heat generation during drilling that include drilling depth, drill flute geometry and design, drill wear, bone characteristics, drilling speed, axial force, drilling protocol, irrigation and drill material (8, 14). Because of the multifactor effect in question, no consensus has been reached regarding surgical protocol that could provide optimum control of the heat generation during implant bed preparation yet. For the physical evaluation of temperature changes during implant osteotomy infrared thermography or thermocouple have been used. Infrared thermography can indirectly measure the thermal profile by means of the changes in a surface through a color scale. The use of thermocouple is an invasive method which the heat sensors required to be placed into the bone close to the implant bed and it can detect the thermal changes (6, 7, 15). Different implant systems show different behaviors in terms of thermal variations during implant osteotomy.

The purpose of this study was to evaluate thermal changes in real-time during implant osteotomy with three implant systems in clinical use at different drilling speeds on bovine bone. Also, we aimed to measure the period over critical threshold during drilling with each drill of each implant system.

MATERIALS AND METHODS

Bone specimen

In this study fresh bovine ribs obtained from a slaughterhouse were used. Before the experiments, the ribs were evaluated by means of cone beam computed tomography (CBCT; rainbow CT, Dentium, Suwon, Korea), and quality/type of the bone was determined according to Hounsfield unit values. By using Rainbow 3D Viewer Imaging Software (Suwan, Korea), the Hounsfield unit values of the regions of interest on the bone were calculated. Regions of the bovine ribs that were classified type 2 and 3 were included in the study. Specimens with a minimum of 10 mm height were selected. Soft tissues removed from the surfaces of the ribs and specimens kept frozen until the experiment. Prior to the experiments, specimens were thawed to room temperature and stored in 0.9 % isotonic saline solution at 37° C for 2 h.

Experimental protocol

Ribs were fixed and secured on a special template to avoid movement during the drilling. Three implant systems Implantium® (Dentium, Seoul, Korea), Straumann® (Institut Straumann AG, Basel, Switzerland) and Anyridge® (Anyridge, Seoul, Korea) were studied. In different implant systems sequential drilling with increasing diameters was applied. In Implantium system drilling started with the D-I2 mm drill and ended with the final drill of D-4.3 mm (D-I2, D-3.4, D-3.8, D-4.3). In Straumann system drilling started with the S-2.2 mm drill and ended with the final drill of S-4.2 mm (S-2.2, S-2.8, S-3.5, S-4.2). In Anyridge system drilling started with the M-2 mm drill and ended with the final drill of 4.3 mm (M-2, M-2.8, M-3.3, M-3.8, M-4.3). For each drill, the thermal changes and duration of the generated heat over 47˚C were evaluated at three different drilling speeds (150, 250, and 400 rpm). Preparations were performed by using A MEG-Engine physiodispenser (Anyridge, Seoul, Korea) and a handpiece (Anthogyr Mont Blane, Anthogyr, France) according to the instructions of the manufacturer. Drilling depth set as 10 mm and controlled by a stopper. A gap of 10 mm also remained between

Speed (rpm)	N	Drill	Maximum Temperature (˚C)	
			Mean ± SD	Median (Min-Max)
150	30	D-I2	41.24±1.80	(41.81) 38.41-43.59^{a}
	30	D-3.4	50.06±4.83	(50.01) 42.86-56.35^{b}
	30	D-3.8	41.92±1.64	(41.99) 39.59-44.98^{ac}
	30	D-4.3	39.35±0.36	(39.23) 38.74-40.02^{d}
	30	S-2.2	41.03±1.46	(41.01) 38.96-43.16^{ace}
	30	S-2.8	37.33±1.57	(37) 35.01-39.74^{df}
	30	S-3.5	41.15±2.17	(41.40) 37.56-45.96^{aceg}
	30	S-4.2	37.12±2.31	(37.82) 33.65-41.60^{dfh}
	30	M-2	41.11±1.29	(41.02) 38.96-43.16^{acegi}
	30	M-2.8	42.16±2.07	(41.37) 39.88-45.98^{acegij}
	30	M-3.3	39.92±0.75	(39.75) 38.40-41.26^{adeghijk}
	30	M-3.8	40.86±1.23	(40.62) 38.86-43.87^{acegijkl}
	30	M-4.3	42.39±1.85	(41.99) 39.66-45.99^{abcegijl}
250	30	D-I2	46.10±8.22	(41.73) 38.70-63.98^{a}
	30	D-3.4	41.75±1.74	(41.23) 39.66-45.49^{a,b}
	30	D-3.8	48.02±6.23	(45.15) 41.76-57.74^{a,c}
	30	D-4.3	43.45±1.38	(43.91) 40.28-45.81^{a,b,c,d}
	30	S-2.2	45.01±1.64	(44.43) 42.60-49.87^{a,b,c,d,e}
	30	S-2.8	52.80±5.49	(52.12) 43.87-60.76^{c,e,f}
	30	S-3.5	58.71±4.33	(57.07) 53.60-65.63^{f,g}
	30	S-4.2	38.95±2.28	(38.30) 36.12-42.87^{b,h}
	30	M-2	41.46±1.73	(41.15) 39.30-45.51^{a,b,d,e,h,i}
	30	M-2.8	74.19±6.80	(73.65) 66.51-86^{f,g,j}
	30	M-3.3	42.18±2.59	(42.01) 38.46-46^{a,b,c,d,e,h,k}
	30	M-3.8	67.44±12.69	(69.81) 47.22-82.35^{f,g,j,l}
	30	M-4.3	53.29±2.39	(53.28) 50.07-59.58^{e,f,g,j,l}
400	30	D-I2	59.37±10.28	(63.49) 44.21-74.21^{a}
	30	D-3.4	43.01±3.13	(41.65) 39.86-50.56^{b}
	30	D-3.8	49.39±6.20	(47.81) 41.99-60.75^{ac}
	30	D-4.3	40.83±0.93	(40.91) 39.46-42.65^{bd}
	30	S-2.2	45.47±2.86	(44.96) 42.33-56.41b^{ce}
	30	S-2.8	46.53±6.25	(44.64) 39.37-59.74^{bcef}
	30	S-3.5	48.33±6.79	(49.18) 38.75-58.72^{bcefg}
	30	S-4.2	43.97±1.33	(43.90) 39.02-45.96^{bcefgh}
	30	M-2	41.93±1.12	(41.61) 40.31-44.57^{bdhi}
	30	M-2.8	75.67±9.58	(78.35) 60.09-95.38^{aj}
	30	M-3.3	50.21±7.12	(50.09) 41.55-61.74^{acefghk}
	30	M-3.8	46.59±3.95	(45.91) 42.06-58.08^{bcefghkl}
	30	M-4.3	50.31±7.79	(47.11) 41.36-69.08^{acefghkl}

a-l: Different letters show significant differences

TABLE 1 Maximum temperatures at different speeds

Speed (rpm)	N	Drill	Duration ≥47 ˚C (sec)	
			Mean ± SD	Median (Min-Max)
	30	D-I2	0	0^{a}
	30	D-3.4	2.56±2.44	2.15 (0-6.78)^{b}
	30	D-3.8	0	0^{acdefghijkl}
	30	D-4.3	0	0^{acdefghijkl}
	30	S-2.2	0	0^{acdefghijkl}
	30	S-2.8	0	0^{acdefghijkl}
150	30	S-3.5	0	0^{acdefghijkl}
	30	S-4.2	0	0^{acdefghijkl}
	30	M-2	0	0^{acdefghijkl}
	30	M-2.8	0	0^{acdefghijkl}
	30	M-3.3	0	0^{acdefghijkl}
	30	M-3.8	0	0^{acdefghijkl}
	30	M-4.3	0	0^{acdefghijkl}
	30	D-I2	1.29±2.13	0 (0-6.10)^{a}
	30	D-3.4	0	0^{ab}
	30	D-3.8	1.97±2.69	0 (0-8.83)^{abc}
	30	D-4.3	0	0^{abcd}
	30	S-2.2	0.25±0.43	0 (0-1.22)^{abcde}
	30	S-2.8	2.18±1.33	2.45 (0-4)^{acef}
250	30	S-3.5	4.59±1.44	4.50 (2.40-9.10)^{fg}
	30	S-4.2	0	0^{abcdeh}
	30	M-2	0	0^{abcdefhi}
	30	M-2.8	11.40±1.93	11.45 (8.24-15.30)^{gj}
	30	M-3.3	0	0^{abcdehik}
	30	M-3.8	10.21±4.15	10.59 (1.66-15.64)^{gjl}
	30	M-4.3	9.13±2.38	8.76 (5.90-13.40)^{gjl}
	30	D-I2	9.36±5.88	12.27 (0-16.43)^{a}
	30	D-3.4	0.31±0.94	0 (0-3.46)^{ab}
	30	D-3.8	3.34±3.99	0.77 (0-11.50)^{abc}
	30	D-4.3	0	0^{abcd}
	30	S-2.2	0.86±1.62	0 (0-5.90)^{abcde}
	30	S-2.8	1.77±2.67	0 (0-8.66)^{aef}
400	30	S-3.5	2.91±3.08	2.36 (0-9.20)^{fg}
	30	S-4.2	0	0^{abcdeh}
	30	M-2	0	0^{abcdehi}
	30	M-2.8	15.63±3.81	15.31 (9.14-25.66)^{gj}
	30	M-3.3	2.59±2.74	2.11 (0-8.46)^{abcdehik}
	30	M-3.8	2.74±3.35	0 (0-9.14)^{gjl}
	30	M-4.3	3.83±4.16	2.33 (0-11.98)^{gjl}

a-l: Different letters show significant differences

TABLE 2 Duration ≥47 ˚C at different speeds

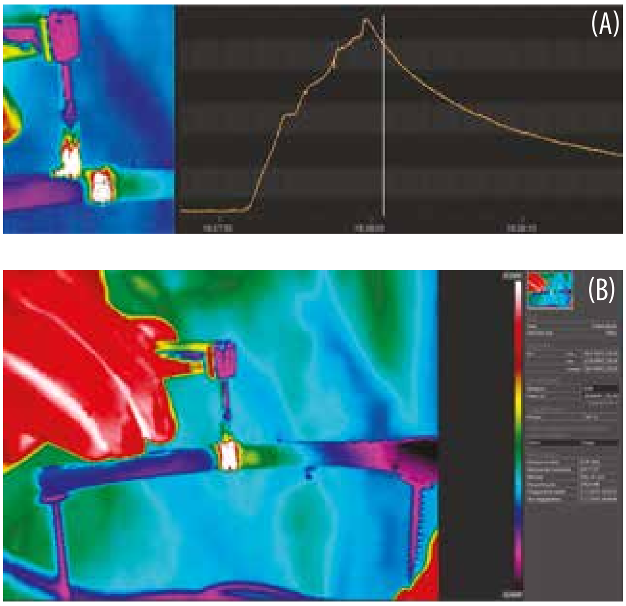


FIG. 1 A: Illustration of the measurement of the generated heat with thermal imaging camera, B: Example for the measurement of the heat generated by S-3.5 drill at 400 rpm

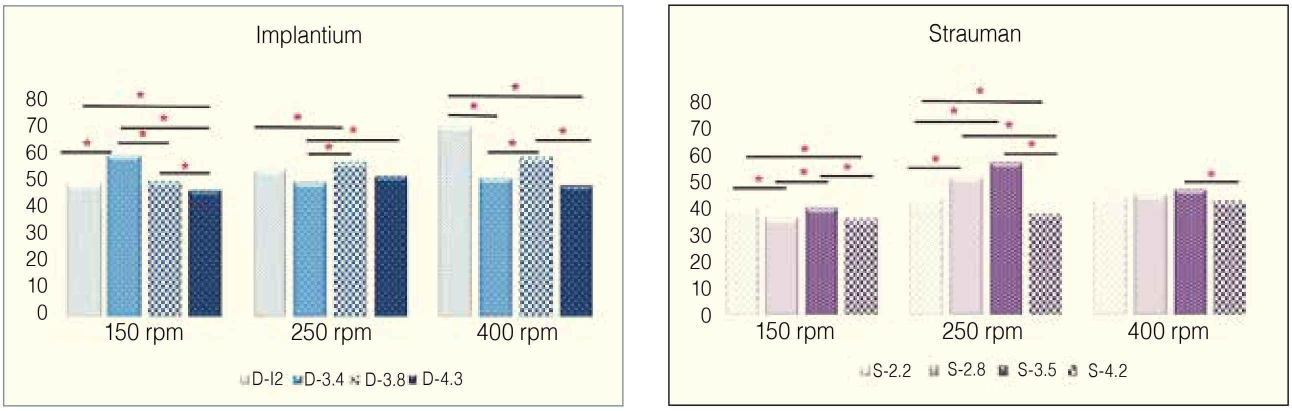
each osteotomy sites, and no irrigation was performed during the drilling procedures. Each protocol was repeated 30 times and a total of 90 osteotomy preparations were created on bovine ribs. During preparations, real time evaluations of the heat generated and the duration of the generated heat over 47˚C were made by using a thermal imaging camera (FLIR T450sc, FLIR Systems Inc., Wilsonville, OR, USA). Thermal imaging camera was also fixed to the special template that the ribs have fixed to ensure standardization of the measurements during preparation (Fig. 1). Osteotomy preparations were performed by the same experienced clinician in implantology to reproduce the clinical situations.

Statistical analysis

Statistical analyses were performed with the IBM SPSS Statistics for Windows software (version 23.0, IBM Corp, Chicago, USA). Data were expressed as mean (SD) and median (Min-Max). The Shapiro-Wilk test was used to evaluate the normality of the data. Kruskal-Wallis test with pairwise comparisons was used to evaluate the maximum temperature and duration of the generated heat over 47˚C for each drill and speed. All tests were two-tailed, and $p< 0.05$ were accepted as significant.

RESULTS

Each protocol was repeated 30 times and a total of 90 implant beds were created on bovine ribs. The mean (SD) and median (Min-Max) values of maximum temperature, duration of the generated heat over 47˚C for each drill in each speed and significant differences among drills were recorded (Table 1, 2, Fig. 2). In terms of the maximum



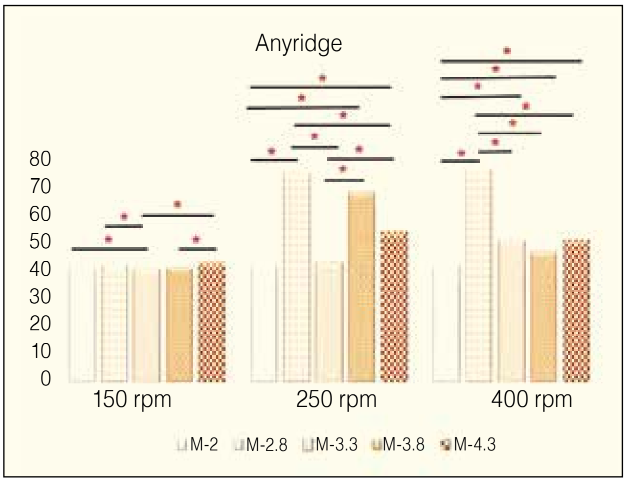


FIG. 2 Comparison of the maximum heat generated at different speeds among the drills of each implant system: **A.** Implantium, **B.** Strauman, **C.** Anyridge.

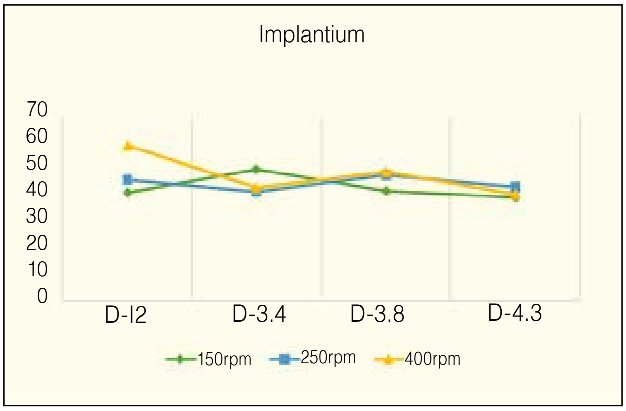
temperature in different drilling speeds for each drill no significant differences were observed for D-I2 between 150 and 250 rpm (p=0.226); for D-3.4 between 250 and 400 rpm (p=0.279); for D-3.8 between 250 and 400 rpm (P=0.546); for S-2.2 between 250 and 400 rpm (P=1.000); for S-4.2 between 150 and 250 rpm (p=0.279); for M-2 between 150 and 250 rpm (P=1.000), 150 and 400 rpm (P=0.061), 250 and 400 rpm (P=0.194), for M-2.8 between 250 and 400 rpm (P=1.000); for M-4.3 between 250 and 400 rpm (P=0.082), while all other measurements for each drill between different speeds showed significant differences (p<0.05) (Fig. 3). In terms of the duration of the generated heat over 47˚C for each drill in each speeds no significant differences were observed for D-I2 between 150 and 250 rpm (p=0.136); for D-3.4 between 250 and 400 rpm (P=1.000); for D-3.8 between 250 and 400 rpm (P=0.483); for D-4.3 between 150 and 250 rpm (p=1.000), 150 and 400 rpm (p=1.000), 250 and 400 rpm (p=1.000); for S-2.2 between 250 and 400 rpm (P=1.000); for S-4.2 between 150 and 250 rpm (p=1.000), 150 and 400 rpm (p=1.000), 250 and 400 rpm (p=1.000); for M-2 between 150 and 250 rpm (p=1.000), 150 and 400 rpm (p=1.000), 250 and 400 rpm (p=1.000); for M-3.3 between 150 and 250 rpm (P=1.000), while all other measurements for each drill between different speeds showed significant differences (p<0.05) (Fig. 4).

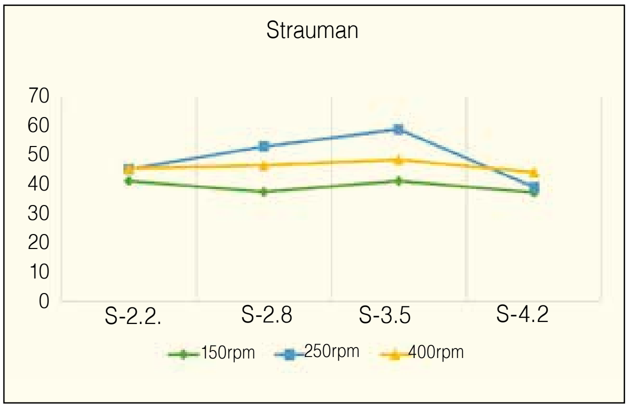
DISCUSSION

Since the bone has low thermal conductivity, overheating over the critical threshold of 47°C during the preparation of the implant site can result in necrosis of the bone cells, deteriorated healing and ultimately failure of the dental implants. Thus, the implant bed preparation has particular importance in terms of preserving the vitality of the cells of bone tissue that participate in the osseointegration (15, 16). In the present in vitro study heat generation in three different implant systems during conventional drilling approach was investigated at different drilling speeds. The implant beds were prepared by the same experienced operator in implantology for standardization and simulating the real time clinical conditions.

To date different bone models that include polyurethane bone blocks (7, 15, 17), resin models (18) and bovine or porcine bones (19-21) have been used to explore the heat generation during implant bed preparation. The bovine bone has been a widely accepted model because its similarity with jawbones in terms of density, geometry, and the ratio of cortical/spongy bone. Bovine bone is also cost-effective and easy to provide (3, 20). To provide standardization prior to the experiments we evaluated the fresh bovine ribs with CBCT to minimize the differences that may be originated from the bone density and type 2 and 3 bone segments of bovine ribs obtained from the same animal were used.

The thermal changes during implant bed preparation can be influenced by various parameters. Drilling protocol is one of the important factors affecting this process. Conventional drilling protocol which describes sequential drilling with increasing diameter drills to gradually remove the bone is recommended mostly to minimize the thermal changes and also for the control of the axis of the implant during drilling (3, 7, 17). On the other hand, opposite opinions favor that using a series of drills considered time consuming for clinicians and increasing inflammatory





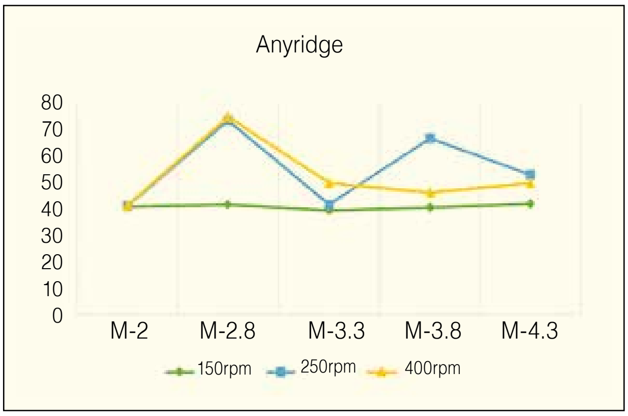


FIG. 3 Temperature variations for each drill with increasing speed: A. Implantium, B. Strauman, C. Anyridge

response as a result of prolonged tissue exposure is also present (20). According to Frosh et al. (17) in small diameter drills transportation of the removed bone out of the implant bed reduced because of their small flutes leading to increased friction and temperature development. Thus, drilling the pre-heated bone with the subsequent drills will cause a further increase in temperature with the use of conventional drilling. Also it is stated that the heat generation is directly related to the time of exposure to the friction forces (22, 23).

In the literature there is still no consensus regarding the drilling protocol that would provide optimal outcomes. El-Kholey et al. (20) tested the simplifying drilling technique by reducing the number of drills in their in-vitro study on bovine ribs and reported that in comparison to conventional drilling simplifying drilling produced the same amount of heat. Similarly, in the study of Mihali et al. (24) which performed on 5 different density bovine and porcine bones it is reported that the simplifying drilling technique is a safe approach for implant site preparation in terms of heat generation. In another study Calvo-Guirado et al. (12) used hybrid drilling technique (biologic plus simplified drilling) on pig ribs without irrigation and found that the increase in the temperature similar to the conventional protocol. On contrary, Mölhlhenrich et al. (7) who explored the influence of bone density and drilling protocol on the heat generation on artificial bone blocks reported that single drilling could generate more heat than traditional drilling, particularly in lower-density bone. Similar results were observed in the study of Lucchiari et al. (3) who explore conventional versus single drill technique on bovine ribs. In this study conventional approach was used to compare the temperature variations among the three different implant systems and the drills used. Heat generation in our groups was observed mostly below the critical threshold in terms of temperature and for the drills that cause excessive temperature increase (M-2.8,

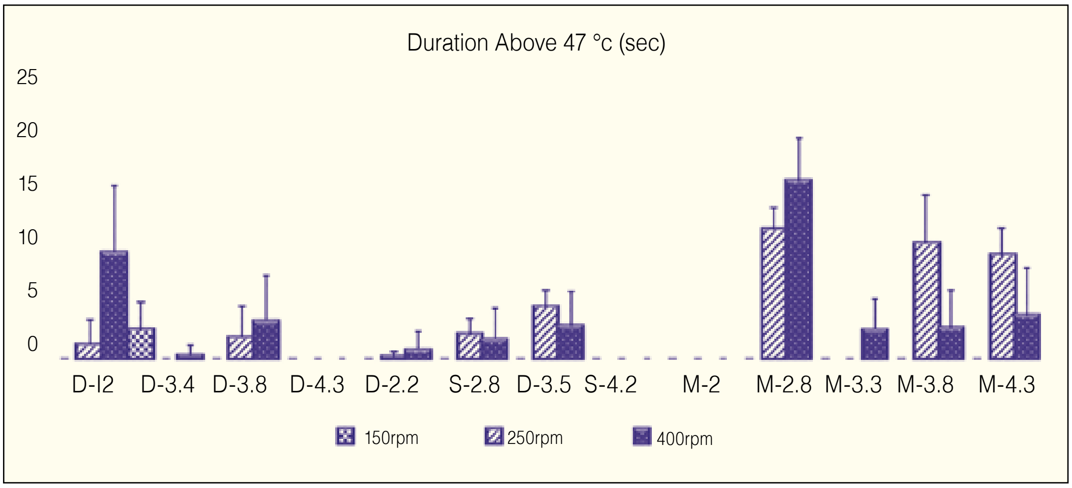


FIG. 4 Comparison of the duration over 47 °C among the drills at different speeds

M-3.8) period of this increased temperature is below one minute. Thus, like the researchers suggesting conventional approach in our groups sequential drilling showed safe results in terms of the heat generation.

Studies in the literature reported that drill diameter has a significant role on the heat generation during osteotomy. Bogovıc et al. (21) explored the effect of drill diameter, drilling force and the drilling speed, and their interactions, on the temperature rise on bovine rib specimens and observed that the increase in the drill-bit diameter from 3.0 to 3.4 mm causes a decrease in the maximum temperature rise while increase in the drill-bit diameter from 3.4 to 3.8 mm causes increase in the maximum temperature rise. They think that the reason for this result is chip jamming in the drill flutes in the smallest drill diameter and larger surface contact between the drill bit and the bone for the largest drill. Bullloch et al. (25) and Watanabe et al. (26) stated that the maximum heat generation will be during the use of the pilot drill while drilling the cortical bone. Flanagan et al. (27) in their in vitro and in vivo study on bovine mandible used increasing diameter drills (2 mm, 2.3 mm, 2.8 mm, 3.3 mm) stated that small diameter drills might generate more heat than larger diameter drills, especially in dense bone. Möhlhenrich et al. (7) investigated the effect bone dentistry on heat generation with drills of 2.2, 2.8, 3.5, and 4.2 mm diameter on four artificial bone blocks (density I–IV), with constant speed and external irrigation. They found that increasing density of bone cause increase in the heat generation but, this effect is reduced with increasing drill diameter. Augustin et al. (28) conducted a study on porcine femora tested 2.5, 3.2 and 4.5 mm diameter drills in different scenarios in terms of speed, feed rate and point angle, and observed that the increase in drill diameter and drill speed caused increase in bone temperature. In the present study in all three-implant systems a uniform trend was not observed with the increase in the diameter of the drills. Especially in anyridge system intermediate drills cause more heat generation when compared to the smallest and the largest drills.

Regarding the drilling speed Iyer et al. (29) measured the heat generated in vivo during osteotomy preparation on rabbit tibial bone at 2000, 30,000, and 400,000 rpm speeds. The authors reported being observed an inverse relationship between drill speed and heat generated. In another study Delgado et al. (19) evaluate the real-time bone temperature changes with different drill designs and different drilling speeds (50/150/300/1200 rpm) in artificial type IV bone using a single-drill protocol. They reported that single-drilling with slow drilling speeds (50, 150, and 300 rpm) without irrigation in type IV bone cause significantly lower temperature changes compared to the temperature changes in 1200-rpm speed. However, Shrawy et al. (30) were measured the heat generated on pig jaw at 1.225,1.667, and 2.500 rpm using 4 implant systems and reported that the mean rise in temperature was lower at 2.500 rpm than at 1.667 or 1.225 rpm. Reingeirtz et al. (31) based on the results of their study proposed that the temperature is increased with the speed between 400 and 7000 rpm, decreased with the speed above 24.000 rpm and thereafter remains constant up to 40,000 rpm. With the increased speed our groups did not showed a uniform increasing or decreasing trend. Each drill of each implant system presents different behaviors against the changes in the speed. However, higher temperature measurements were observed in the speeds of 250 rpm and 400 rpm when compared to the measurements at 150 rpm except the D-3.4 drill.

The period of increased temperature over the critical threshold is another important factor causing thermal damage. Augustin et al. (14) reported that temperature of 50°C will continue for a mean of 21 seconds however, majority of results will be around 50 seconds. In this study maximum duration above 47°C is observed in the M-2.8 at 400 rpm measured as 15.63 seconds. Other measurements of the duration above 47°C were ~10 seconds and below.

Thermocouple and infrared thermography are two different methods that are widely used for the evaluation of the changes in temperature (6, 7, 15). Thermocouple performed a direct measurement with thermocouple probes placed to the bone at distances of 1–0.5 mm from the implant bed and provides an indirect estimate. This is a traumatic method is not appropriate for clinical settings because of the ethical and legal aspects. The change in distance of the sensor 0.3 to 0.7 mm from region of interest has shown a decrease of 2 °C thus this cause low thermal sensitivity. Also, measurements are influenced by the material used, isolation, and depth (4, 15). Infrared thermography is an atraumatic and sensitive method of measuring overall thermal profile and has been used for clinical real time evaluation of temperature variations in bone (4, 6, 22, 32). Despite the thermocouples infrared technology can evaluate the overall thermal profile, and considered as more accurate with a lower probability of error (7, 33). Therefore instead of thermocouple we prefer thermal imaging camera to perform the atraumatic measurement of thermal profile.

When interpreting the results of this study some limitations needs to be bear in mind. In our study bovine ribs which differ from the human bone, in terms of blood flow, cortical thickness, water content, and thermal conductivity were used. Also only type 2 and 3 bone tested at a single depth of 10mm in terms of heat generation. Although the same experienced operator performed all the osteotomies, slight variations may occur in terms of the load applied as in clinical practice.

With the limitation of this study some conclusions may be reached. In this study different drills of the different systems exhibit different behaviors when considering the parameters evaluated. Temperature observed to be increased over at 250 and 400 rpm when compared to the 150 rpm. However, at 250 and 400 rpm temperature variations did not follow a uniform trend and show difference based on the drill used. Similarly, in terms of diameter change in the temperature also observed specific to the drill used. Maximum generated heat observed in

D-I2 and D-3.4 for Implantium system, in S-2.8 and S-3.5 for Straumann system, in M-2.8 and M-3.8 for Anyridge system. Period over critical threshold also below the critical limit for all measurements. In can be concluded based the results of this study that when considering the temperature increase and the time spent for preparation over critical threshold the evaluated implant systems at different speeds were in safe limit clinically.

Conflict of interest

None.

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