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The influence of drill length and irrigation system on heat production during osteotomy preparation for dental implants: an *ex vivo* study

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Key words: dental implant, drill length, heat generation, irrigation system, osteotomy

Abstract

Objective: This study aimed to measure the influence of drill length and irrigation system on heat production during osteotomy preparation for dental implants using bovine bone rib as experimental model.

Materials and methods: Three groups were created: Group 1: drilling with three consecutive burs with double irrigation (internal and external) for a 4.0 mm conical implant; and Group 2 and Group 3: drilling with three consecutive burs with external irrigation for a 4.1 mm cylindrical implant and for a 4.3 mm conical implant, respectively. Four lengths were tested: 10, 12, 14 and 16 mm; in site prepared on bovine ribs using a surgical unit linked to a testing device, to standardize and simulate implant drilling procedures. Bone temperature variations were recorded using three thermocouples in different positions as of the crestal bone: 2 mm, position (p1); 7 mm, position 2 (p2); and 12 mm, position 3 (p3).

Results: The highest temperature changes were invariably recorded during the process of withdrawal. Significantly lower temperature changes ($P < 0.02$) could be recorded at maximum drilling depths during the shearing process regardless of drilling depth or irrigation method. Double irrigation was associated with significantly lower temperatures compared with external irrigation by the use of implant drills ($P < 0.01$).

Conclusions: Within the limitations of this *ex vivo* study was possible concluded that the use a double irrigation system in multiple conventional drill for osteotomy can decrease the heat generation when increase the drill length.

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The concept of osseointegration implies bone establishes a direct contact with the surface of the implant with no intervening fibrous tissue (Schroeder et al. 1981; Lioubavina-Hack et al. 2006). The basic requirements involved in successful osseointegration are atraumatic surgical technique and the initial stability of the implant during the surgery (Cardemil et al. 2009; Gehrke et al. 2015), which are directly related to the osteotomy procedure for preparing the site prior to installation of the implant.

The overheating of surrounding bone due to attrition of drills while rotating can cause a local bone necrosis, influencing biological stability through the deterioration of the organic portion of the bone tissues (Leunig & Hertel 1996; Pandey & Panda 2013), which may result in a fibrous tissue interpositioned at the implant–bone interface, compromising the osseointegration success (Tehemar 1999; Van Staden et al. 2008). The largest amount of heat generated results from the friction of the drill with dense cortical bone (Brisman 1996; Pandey & Panda 2013); in fact, it is known that medullar bone has a higher capacity of dissipating heat than cortical one (Eriksson et al. 1984a,b). Several factors have been reported to affect temperature variation during implant site preparation such as drilling depth, drill geometry and design (Ercoli et al. 2004), sharpness of the cutting drill (Chacon et al. 2006; Tuijthof et al. 2013), variations in cortical thickness (Eriksson et al. 1984a,b), bone density (Albrektsson & Albrektsson 1978; Yacker & Klein 1996), drilling speed (Sharawy et al. 2002; Karaca & Aksakal 2013), pressure applied to the drill (Karaca & Aksakal 2013; Mishra & Chowdhary 2014; Stelzle et al. 2014), use of incremental vs. one step drilling (Kondo et al. 2000; Gehrke et al. 2015), continuous or intermittent movements, internal or external irrigation (Gehrke et al. 2013) and equipment used (Reingewirtz et al. 1997).

The tip of the surgical drills is its most active part, which is supposedly found greater resistance during their use for drilling the bone sites. During the osteotomy with drill without internal irrigation, as this is working inside the bone, the irrigating solution is not enough to make that location cooling, and supposedly the greater the length of drilling, the greater the possibility of heating. However, most studies do not clearly show the relationship between the heating generation and the length of the drills. Thus, this study aimed to measure the influence of drill length and irrigation system on heat production during osteotomy preparation for dental implants using bovine bone rib as experimental model.

Material and methods

This *ex vivo* study was performed on 48 adult bovine rib bone in sections that measured approximately 100 × 10 × 20 mm. The samples were chosen so as to have similar geometry and thickness of cortical layer (Fig. 1).

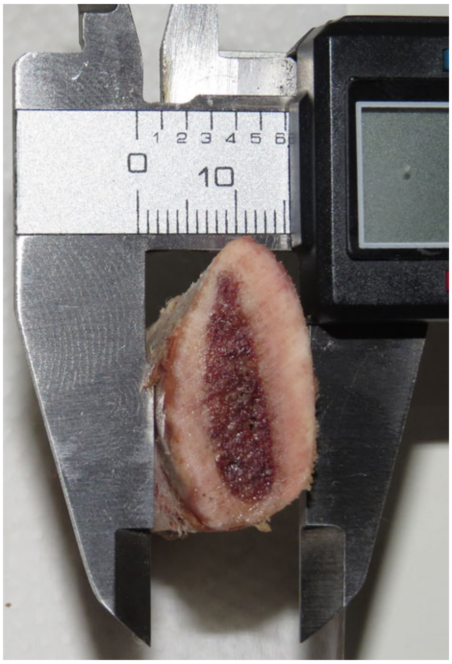

Fig. 1. Image of the bovine bone used in the study.

An apparatus composed of a control panel with a programmable logic controller (PLC) and a step motor with a man–machine interface (MMI) was used in the experiments (Gehrke et al. 2013). These devices were used to produce continuous drilling movements, which were predetermined (position, depth and load) with high precision by the investigator. A vise was used to stabilize bone samples while drilling. The drill sequence and speed during the surgical osteotomies were adjusted as recommended by each manufacturer, with a saline solution irrigation flow of 50 ml/min (at room temperature of 20 ± 2°C), as coupled to a handpiece with a 20 : 1 reduction and a predetermined load of 2 kg, linked to the step motor. Each set of drills were used only five osteotomies to avoid the influence of the wear on the results of the study. In this study, a load of 2 kg was used, according to the procedures of previous similar studies (Gehrke et al. 2013; Möhlhenrich et al. 2015). As a whole, the entire apparatus reduced the possibility of human error during the experiment.

Three groups were performed: Group 1: drill sequence for a conical 4.0-mm implant, Implacil De Bortoli (São Paulo, Brazil): tapered 2 mm (5.031 g), 3.5 mm (8.80425 g) and 4.0 mm (10.062 g) (Implacil Information on the Surgical Procedures 2015). Group 2: drill sequence for a cylindrical 4.1 mm standard implant, Straumann (Basel, Switzerland): drill diameters were 2.2 mm (used at 1.5741 g), 2.8 mm (1.1269 g) and 3.5 mm (0.97825) (Basic Information on the Surgical Procedures 2012). Group 3: drill sequence for a conical 4.3 mm NobelReplace® implant, Nobel Biocare (Goteborg, Sweden): tapered 2 mm (8.944 g), 3.5 mm (2.50432 g) and 4.3 mm (3.0767 g) (Nobel Replace and Replace SelectTM Tapered 2015). The drills of Group 1 presented a double irrigation (Fig. 2), while in Groups 2 and 3 only external irrigation.

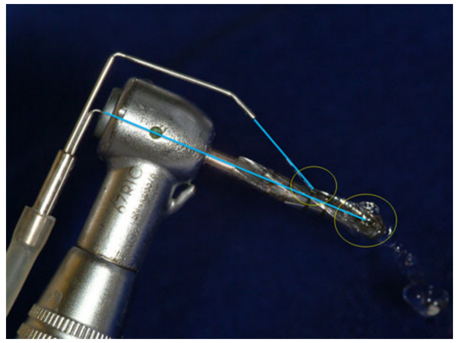

Fig. 2. The drill systems showed the double (internal and external) irrigation.

The lengths evaluated in all groups were as follows: 10 mm (L1), 12 mm (L2), 14 mm (L3) and 16 mm (L4), being that the depth was determined and automated by the controlled drilling apparatus. For each group, 10 perforations were made without irrigation and 10 with irrigation, using a new drill sequence for each situation. The perforations without irrigation were used as control of the process used in this study. A different hole for measurement was used for any drilling procedure, totalizing 240 osteotomies (n = 80 per group). Five osteotomies were made in each rib, and these always in the same group.

For the temperature measurements, three type K thermocouple devices were coupled to digital thermometers with a resolution of 0.1°C and inserted into a hole (1 mm diameter and 2 mm in depth) placed 0.5 mm lateral to the perforations in three positions as of the crestal bone: 2 mm, position (p1); 7 mm, position 2 (p2); and 12 mm, position 3 (p3). This configuration is illustrated in Fig. 3 and 4. Following one perforation, the subsequent was not performed until the temperature was returned to normalcy (20 ± 2°C).

Parameters evaluation and statistical analysis

Statistical analysis was performed using PASW Statistics v.22.0.0 software (SPSS Inc., Chicago, IL, USA) for Mac. Values were recorded as mean, medians and standard deviation. Nonparametric Friedman test and Wilcoxon signed-rank test was applied for more than two was applied to the comparison of medians and to quantify relationships between differences ($P < 0.05$). Bonferroni post hoc test was applied to correct the comparison. The level of significance was set at $P < 0.05$. For all the tests performed, the confidence level chosen was 95%.

Results

The mean temperatures measured in the three groups and the mean differences respect to baseline values (ΔT) with CI 95% considering the drilling with and without irrigation in the three measured positions are reported in Tables 1–4 separated by the drill length. The box-plots graph of Figs 5 and 6 showed the overall mean between the three positions for the groups in the four lengths tested.

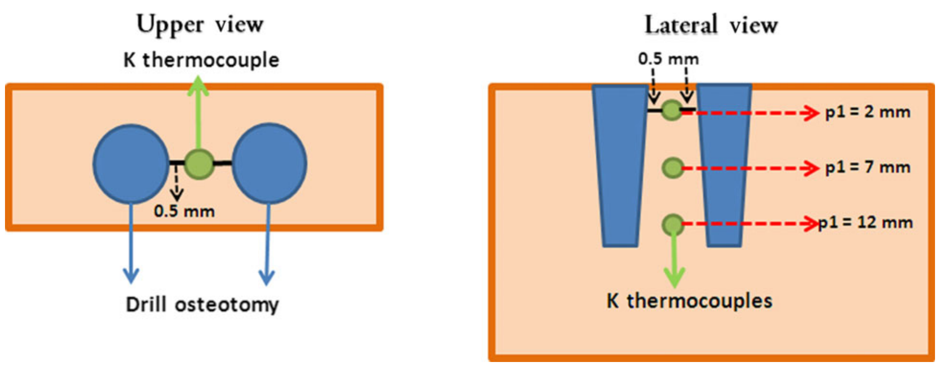

Fig. 3. Scheme of the positions of type K thermocouples installed to measure the temperature during drilling.

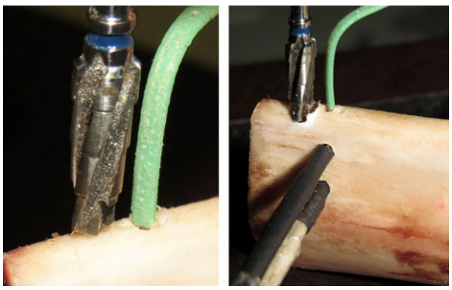

Fig. 4. The type K thermocouples positioned to measure the temperature.

In all groups, irrigation caused a significant lower temperature change respect to samples in which irrigation was not used. It was observed that increasing the drill length, the temperature change tends to be increased. Regarding the between-group comparison, group 1 showed significant lower temperature change as compared to groups 2 and 3 in all positions. In the latter, the highest temperatures were achieved, both without and under irrigation. No significant temperature changes were found among groups 2 and 3 both with and without irrigation (the experimental condition most similar to the clinical situation) in all positions measured.

Discussion

In the present study, drills for implant osteotomy with different lengths were compared as concerns the heat generation during the preparation of implant sites using different drill systems with simple and double (internal and external) irrigation in bovine bone samples. This sample model was selected because of the similarities between bovine bone and human mandibular bone in terms of density and relationship between cortical and cancellous bone (Ercoli et al. 2004; Laurito et al. 2010; Sumer et al. 2011; Strbac et al. 2014). From density analysis resulted similar Hounsfield values between human cortical and medullary bone and cortical and medullary bovine bone. Hounsfield units of cortical bone in an average human mandible have been observed to be 1400–1600 with a medullary reading of 400–600 Hounsfield units. The cortical bone in bovine ribs has been demonstrated to be 1400 Hounsfield units and the medullary bone 470 Hounsfield units (Yacker & Klein 1996). Bovine bone has been widely used by other *in vitro* studies because its density, geometry, relationship between cortical and cancellous component could be assimilated to human mandibular bone (Ercoli et al. 2004; Laurito et al. 2010; Sumer et al. 2011; Oliveira et al. 2012).

The distance between probe tip and heat source represents a critical factor to obtain a proper recording temperature. Jochum & Reichart (2000) have shown a decrease of 2°C changing the position of probing device from 0.3 to 0.7 mm from the border of the osteotomies. So, in the present study the thermocouples were positioned in a site at a 0.5 mm distance from the osteotomy, created by a vertical perforation of 1 mm in diameter and 2 mm in depth in the crestal cortical bone and another's two 7 and 12 mm to apical whit the hole made by the lateral portion of the bone. So, the thermocouple measured the actual temperature achieved in the crestal cortical bone and in the medullar area (inside of the bone) during drilling.

The lower density of the medullary component respect to cortical bone offers less resistance to drilling causing less attrition, which can be evidenced by the smaller variation of temperature measurement in this area even without irrigation. The heat generated could be quickly dissipated in the cancellous bone *in vivo* due to the presence of considerable blood flow. Therefore, the temperature changes measured at cortical level give an idea of the highest ΔT during drilling in the bone surrounding the osteotomy site.

Because of the intimate contact present at the bone–drill interface, the irrigation solution may reduce the temperature throughout the whole length of the bony walls. The intermittent use of burs allows the escape of bone chips and access for the irrigation fluid, decreasing the heat generation (Gehrke et al. 2013; Strbac et al. 2015). Whenever continuous drilling is performed, temperature will

***Table 1.* Drilling temperatures and variations from baseline in the length L1 (10 mm)**

	Group 1		Group 2		Group 3			
	No irrigation Mean $\Delta T \pm$ SD (median), °C	With irrigation Mean $\Delta T \pm$ SD (median), °C	No irrigation Mean $\Delta T \pm$ SD (median), °C	With irrigation Mean $\Delta T \pm$ SD (median), °C	No irrigation Mean $\Delta T \pm$ SD (median), °C	With irrigation Mean $\Delta T \pm$ SD (median), °C	*P* value (a)	*P* value (b)
Position p1	5.9 ± 1.26 (5.91)[b1]	2.1 ± 0.67 (2.07)	8.1 ± 1.22 (8.12)[a1,b2]	2.6 ± 1.85 (2.59)	8.2 ± 1.23 (8.19)[a2, b3]	2.6 ± 0.90 (2.61)	a1 = 0.023 a2 = 0.018	b1 = 0.011 b2 = 0.015 b3 = 0.023
Position p2	5.2 ± 0.95 (5.24)[b1]	1.7 ± 0.59 (1.66)	7.5 ± 1.72 (7.48)[a1, b2]	2.7 ± 1.01 (2.72)	7.6 ± 0.81 (7.59)[a2,b3]	2.3 ± 0.66 (2.31)	a1 = 0.029 a2 = 0.021	b1 = 0.008 b2 = 0.022 b3 = 0.016
Position p3	4.5 ± 1.44 (4.48)[b1]	1.5 ± 0.58 (1.53)	7.6 ± 1.37 (7.60)[a1,b2]	3.0 ± 0.98 (3.02)	7.3 ± 1.27 (7.31)[a2,b3]	2.2 ± 0.92 (2.22)	a1 = 0.031 a2 = 0.018	b1 = 0.014 b2 = 0.011 b3 = 0.033

T, temperature variation; SD, standard deviations; CI, confidence intervals.

Table 2. **Drilling temperatures and variations from baseline in the length L2 (12 mm)**

Group 1		Group 2		Group 3			
No irrigation Mean $\Delta T \pm$ SD (median), °C	With irrigation Mean $\Delta T \pm$ SD (median), °C	No irrigation Mean $\Delta T \pm$ SD (median), °C	With irrigation Mean $\Delta T \pm$ SD (median), °C	No irrigation Mean $\Delta T \pm$ SD (median), °C	With irrigation Mean $\Delta T \pm$ SD (median), °C	*P* value (a)	*P* value (b)
Position p1							
6.0 ± 1.17 (6.03)^{b1}	2.2 ± 1.25 (2.22)	8.2 ± 1.09 (8.22)^{a1,b2}	2.6 ± 1.00 (2.66)	8.3 ± 0.86 (8.31)^{a2,b3}	2.6 ± 1.33 (2.61)	a1 = 0.014 a2 = 0.012	b1 = 0.017 b2 = 0.029 b3 = 0.009
Position p2							
5.8 ± 1.43 (5.77)^{b1}	1.9 ± 1.24 (1.88)	7.6 ± 1.85 (7.67)^{a1,b2}	2.5 ± 1.10 (2.51)	7.5 ± 1.74 (7.51)^{a2,b3}	2.4 ± 1.42 (2.40)	a1 = 0.024 a2 = 0.016	b1 = 0.027 b2 = 0.010 b3 = 0.018
Position p3							
4.5 ± 1.42 (4.51)^{b1}	2.0 ± 1.20 (2.09)	7.7 ± 1.60 (7.69)^{a1,b2}	2.7 ± 1.10 (2.74)	7.3 ± 1.62 (7.29)^{a2,b3}	2.3 ± 1.21 (2.32)	a1 = 0.027 a2 = 0.032	b1 = 0.019 b2 = 0.015 b3 = 0.013

T, temperature variation; SD, standard deviations; CI, confidence intervals.

Table 3. **Drilling temperatures and variations from baseline in the length L3 (14 mm)**

Group 1		Group 2		Group 3			
No irrigation Mean $\Delta T \pm$ SD (median), °C	With irrigation Mean $\Delta T \pm$ SD (median), °C	No irrigation Mean $\Delta T \pm$ SD (median), °C	With irrigation Mean $\Delta T \pm$ SD (median), °C	No irrigation Mean $\Delta T \pm$ SD (median), °C	With irrigation Mean $\Delta T \pm$ SD (median), °C	*P* value (a)	*P* value (b)
Position p1							
5.8 ± 1.60 (5.81)^{b1}	2.3 ± 1.07 (2.31)	8.2 ± 1.53 (8.23)^{a1,b2}	2.6 ± 1.03 (2.63)	8.2 ± 0.97 (8.23)^{a2,b3}	2.4 ± 1.17 (2.38)	a1 = 0.021 a2 = 0.035	b1 = 0.009 b2 = 0.012 b3 = 0.011
Position p2							
5.4 ± 1.27 (5.38)^{b1}	1.9 ± 0.80 (1.86)	7.8 ± 1.48 (7.81)^{a1,b2}	2.5 ± 1.17 (2.51)	7.9 ± 1.21 (7.97)^{a2,b3}	2.3 ± 1.07 (2.32)	a1 = 0.017 a2 = 0.022	b1 = 0.032 b2 = 0.019 b3 = 0.011
Position p3							
4.1 ± 0.90 (4.10)^{b1}	1.8 ± 0.94 (1.77)	7.6 ± 1.36 (7.59)^{a1,b2}	2.3 ± 1.22 (2.31)	7.4 ± 1.18 (7.41)^{a2,b3}	2.1 ± 1.02 (2.07)	a1 = 0.011 a2 = 0.033	b1 = 0.007 b2 = 0.012 b3 = 0.015

T, temperature variation; SD, standard deviations; CI, confidence intervals.

rise not only because of the inaccessibility of cooling fluid, but also because of the clogging effect of the bone debris on the cutting edge of the drill, which will decrease its cutting efficiency and consequently increase the time required for bone bed preparation (Tehemar 1999; Laurito et al. 2010). In this experiment, we used a continuous drilling protocol until site preparation was complete.

Different clinical and experimental studies have been conducted to evaluate the role of drilling speed; however, this issue is still being debated. Some authors have reported no significant difference in bone repair with use of different drilling speeds (Ribeiro Junior et al. 2007). Other investigations have shown a reduction of frictional heat arising from bone drilling when low rotational speed is used (Pirjamalineisiani et al. 2015). In contrast, Iyer et al. (1997) stated that the rate and quality of healing are better around osteotomies prepared at high speed rather than around osteotomies performed at intermediate or low speeds. However, different factors could contribute to such contradictory findings, such as the study models, site of drilling, features of the drill and methods of examinations. Abouzgia & James (1997) postulated that neither the manufacturer's stated speed nor the measured free running speed could match the actual speed of the drill, as reduction in the drilling speed during cutting (up to 50%) can occur. Authors have demonstrated that high-torque, low-speed handpiece running between 10.06 and 27.95 g are considered the ideal instruments for implant bed preparation (Möhlhenrich et al. 2015). However, in the present study the drill speed used was in accordance with the recommendations to each brand.

In respect to the irrigation method, Gehrke et al. (2013, 2014) showed that the double irrigation system generates a smaller increase in temperature during the osteotomies, either using drills as trephines. The results obtained in this study corroborate these findings because the measured range of values, regardless of the length of the drills, were significantly lower for cutters with double irrigation, with a general average of approximately 12% low in the group 1 related to groups 2 and 3. Although other study has related that the double irrigation system is unjustifiable (Benington et al. 2002), most studies comparing internal irrigation systems with dual irrigation systems found more favorable results in the drills with internal and external irrigation (Augustin et al. 2012; Gehrke et al. 2013, 2014).

Direct and indirect methods are commonly used to record temperature rise during drilling. Thermocouple is the direct method based on heat sensitive probe connected to thermometers or computer software. Probe isolation technique, depth of recording, material of the sensor element, precision of the device and other factors may influence thermocouple results; therefore, this method is under discussion. The thermocouple could record only spot temperature and seems to be inadequate to detect overall thermal profile and heat leakage

Table 4. **Drilling temperatures and variations from baseline in the length L4 (16 mm)**

	Group 1		Group 2		Group 3			
	No irrigation Mean $\Delta T \pm$ SD (median)	With irrigation Mean $\Delta T \pm$ SD (median)	No irrigation Mean $\Delta T \pm$ SD (median)	With irrigation Mean $\Delta T \pm$ SD (median)	No irrigation Mean $\Delta T \pm$ SD (median)	With irrigation Mean $\Delta T \pm$ SD (median)	*P* value (a)	*P* value (b)
Position p1	5.7 ± 0.93 (5.69)^{b1}	2.2 ± 1.13 (2.22)	8.2 ± 1.22 (8.03)^{a1,b2}	2.4 ± 1.45 (2.45)	8.3 ± 1.37 (8.31)^{a2,b3}	2.5 ± 1.3 (2.58)	a1 = 0.032 a2 = 0.026	b1 = 0.027 b2 = 0.012 b3 = 0.032
Position p2	4.8 ± 1.16 (4.82)^{b1}	2.0 ± 1.26 (2.00)	7.8 ± 1.29 (7.79)^{a1,b2}	2.2 ± 1.18 (2.17)	7.6 ± 1.56 (7.67)^{a2,b3}	2.2 ± 1.06 (2.25)	a1 = 0.014 a2 = 0.037	b1 = 0.036 b2 = 0.021 b3 = 0.030
Position p3	4.2 ± 0.95 (4.25)^{b1}	1.6 ± 0.97 (1.69)	7.7 ± 1.30 (7.73)^{a1,b2}	2.2 ± 1.14 (2.22)	7.2 ± 1.18 (7.21)^{a2,b3}	2.0 ± 1.09 (2.07)	a1 = 0.022 a2 = 0.019	b1 = 0.041 b2 = 0.007 b3 = 0.015

T, temperature variation; SD, standard deviations; Comparison inside each group (a) and between irrigation or no irrigation (b).

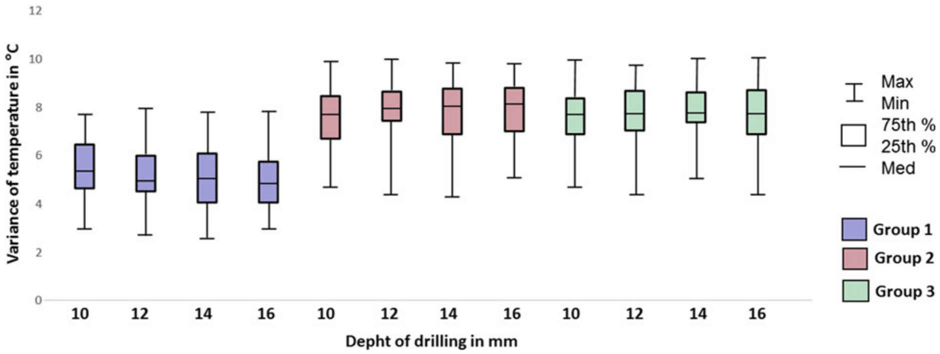

Fig. 5. Box plot of temperature variation at osteotomy in the groups without irrigation using an overall mean of the three measurement positions.

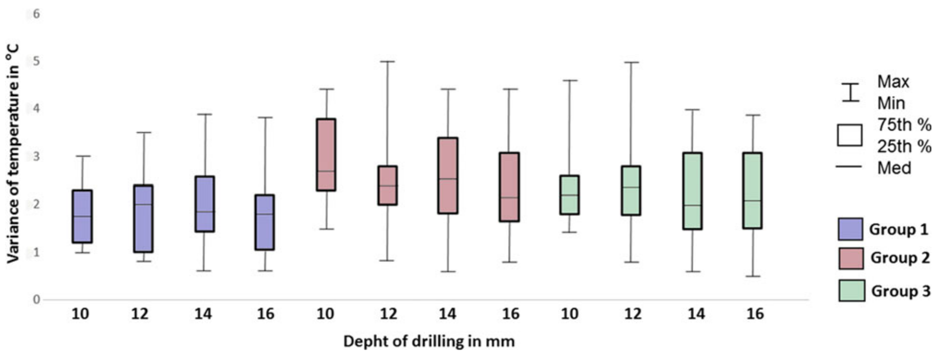

Fig. 6. Box plot of temperature variation at osteotomy in the groups with irrigation using an overall mean of the three measurement positions.

(Tehemar 1999). Infrared thermography is a non-invasive indirect technique, based on the study of energy emitted by electromagnetic radiation. Electromagnetic radiations are emitted by all bodies, and the total energy depends on the absolute temperature of the body (Scarano et al. 2011). Infrared thermography allows for a thermal picture of the drill site and surrounding tissue and is considered more accurate than thermocouple. The cooling irrigation may represent a limit in infrared thermography use, because it could hide the temperature measurements in deeper layers of the implant site preparation (Reingewirtz et al. 1997). Because of this, in the present study were installed three thermocouple sensor type K devices in different levels, thus enabling the measurement of the temperature inside the bone. Scarano et al. (2007) compared the temperature in the cortical bone and in the apical portion of conical and cylindrical drills. They found that the temperature modifications in the apical portion of the drill seemed to be correlated to the drill geometry, suggesting that drill geometry seems to be an important factor in heat generation during implant site preparation.

The results of the present study would suggest that differently drills design may perforate the cortical bone with different incident angles produced by the drill design and length, creating different levels of heat generation. Furthermore, the irrigation method can reduce the heat generated during the osteotomy. To minimize or avoid bone defects and necrosis, dentistry surgeons should consider the optimum drilling parameters.

Conclusion

The present study showed that all systems tested generate a moderate temperature variation during the osteotomy to preparing the implant site with to continuous drilling protocol even if varying the length. Moreover, the use a double irrigation system in multiple conventional drill sequence for osteotomy can decrease the internal thermal heat when increase the drill length.

Conflict of interest statement

The authors declare they have no conflict of interests.

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