Temperature Changes in Cortical Bone after Implant Site Preparation Using a Single Bur versus Multiple Drilling Steps: An In Vitro Investigation

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ABSTRACT

Objectives: The study aims to test the hypothesis of no differences in temperature variation by using a single bur for implant site preparation as compared with conventional drilling sequence using multiple burs with incremental diameter.

Materials and Methods: Synthetic blocks of bone (type I density) were used for drilling procedures.

Three Groups Were Evaluated: Group 1 and Group 2 – drilling with three consecutive burs for a 4.1 mm cylindrical implant and for a 4.3 mm conical implant, respectively; Group 3 – drilling with a single bur for a 4.2 mm conical implant. For each group, 20 drilling procedures were performed without irrigation and 20 with external irrigation. The temperature in the cortical bone during osteotomy for implant site preparation was measured through a thermocouple.

Results: The mean temperatures and standard deviations for the drilling without irrigation were: 25.5 ± 1.24°C for Group 1; 28.1 ± 1.76°C for Group 2; 26.5 ± 1.79°C for Group 3. Considering the drilling with irrigation, the mean values and standard deviations were: 20.4 ± 1.17°C for Group 1; 22.2 ± 1.38°C for Group 2; 20.2 ± 0.83°C for Group 3. Groups 1 and 3 yielded similar results, while Group 2 displayed significantly higher temperature increase than the other two groups.

Conclusions: The single bur drilling protocol did not produce greater bone heating than the conventional protocol and may be considered a safe procedure.

KEY WORDS: bone surgery, cortical bone, dental implants, irrigation methods, osteotomy, thermocouple

INTRODUCTION

One of the issues that may contribute to a successful osseointegration of dental implants is to minimize surgical trauma to bone tissue.[1] While preparing implant site, the overheating of surrounding bone due to attrition of burs during drilling can cause local bone necrosis, through the deterioration of the organic component of the bone.[2,3] This situation can have a direct implication in osseointegration process, influencing peri-implant bone loss rate and implant survival.[4–7]

Albrektsson and colleagues suggested that the success of osseointegration depends on six factors: implant biocompatibility, design, surface, state of the host bed, surgical technique, and loading conditions.[8] More specifically, the critical modifiable factors are the macro and microgeometry, excessive surgical trauma,

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DOI 10.1111/cid.12172

prosthesis overload, misfit of suprastructures, or surgical site infection.[9,10]

Several studies have evaluated the effects of overheating on surrounding bone, such as necrosis, fibrosis, bone cystic degeneration, and a general decrease of the osteoblastic activity.[4,11,12] These are mainly caused by physical characteristics of the bone itself, which has a very low thermal conductivity that prevents the heat dissipation while drilling. Also, the inner structure of the bone has importance in determining the reaction to heat stress. In fact, it was known that medullar bone, due to its greater vascularization, has a higher capacity of dissipating heat than cortical bone.[1,12]

It was demonstrated that the temperature limit without damaging the tissues during the preparation of the implant site is between 44°C and 47°C. and that the drilling time must be less than 1 minute.[13,14] The heat production during drilling has also been evaluated as a function of drill design,[15–18] repeated utilization of drill units,[19] and irrigation method.[20,21]

Several devices and techniques were proposed in order to control the thermal damage to bone, reducing the heat due to drilling. External irrigation is directed to the bur and dispersed over the cortical bone while preparing implant site.[8,20,22] Internal irrigation consists of water delivered through a canal that is internal to the bur itself, ending with a hole and allowing to directly cool the bur–bone interface.[20,23] A combination of both irrigation systems was also described in literature.[24]

Moreover, many devices and techniques were adopted to measure the physical amount of heat generated during the drilling. Infrared thermography was described as an indirect method allowing the measurement of the temperature, detectable on the surface of a body through a color scale.[18,22] Also, thermocouples were used, placed close to the site of bone drilling.[8,15,24,25] Thermocouples are based on the differential of electrical potential between two metals and they are a sensible detector for measuring temperature.

Even though there are studies investigating the effect of different drilling protocols on osseointegration, little or no data are available regarding the rate in which the drilling site diameter is incrementally increased prior to implant placement. As anecdotally, this procedure has been performed in an incremental drill diameter fashion in an attempt to minimize bone damage during its instrumentation. There is no evidence in the literature on the optimal drilling protocol that would result in successful osseointegration in clinical reality. Recently, a published study showed an excellent success rate with the installation of implants using simplified osteotomy in which a single drilling step is performed.[26] This also brings considerable advantages in terms of time, considering that several drilling protocols require a number of time-consuming steps. However, a balance should exist between the accuracy of the implant site in terms of angulation, size, and shape for an optimal implant accommodation, and the total time required. The latter should not be too long for avoiding prolonged exposure of the surgical site and thermal trauma to bone tissue due to repeated drill procedures. It appeared of great interest to investigate if reducing the number of drilling steps and, in particular, using a single high-performance drill, would provide results comparable with the conventional drilling sequence in terms of bone heating.

Thus, the aim of the present in vitro study was to measure the bone temperature during the drilling, comparing a simplifying protocol consisting of one single drill versus multiple conventional drilling for implant site preparation. The null hypothesis was that in using a single drilling step, no difference in heating of the bone surrounding the implant site occurs, with respect to using conventional multiple-step drilling.

MATERIALS AND METHODS

An apparatus was prepared ad hoc for this experiment. It was composed of a control panel with a programmable logic controller and a step motor with a man–machine interface. These devices were used to produce continuous drilling movements, which were predetermined (position, depth, and load) with high precision by the investigator. A device was used to stabilize bone samples while drilling. The surgical osteotomies were adjusted as recommended by each manufacturer, with a saline solution irrigation flow of 50 mL/min (at room temperature ~19°C), as coupled to a handpiece with a 20:1 reduction and a predetermined load of 2 kg, linked to the step motor. In the present study, a load of 2 kg was used, according to the procedures of other authors.[23,24] The speed used was as recommended by each implant system. As a whole, the entire apparatus reduced the possibility of human error during the experiment.

Three groups were considered:

Group 1: Drill sequence for a cylindrical 4.1 mm standard implant, Straumann (Basel, Switzerland): drill diameters were 2.2 mm (used at 800 rpm), 2.8 mm (600 rpm), and 3.5 mm (500 rpm).[27] The length was 12 mm.

Group 2: Drill sequence for a conical 4.3 mm NobelReplace® implant, Nobel Biocare (Göteborg, Sweden): tapered 2 mm (2000 rpm), 3.5 mm (800 rpm), and 4.3 mm (800 rpm).[28] The length was 13 mm.

Group 3: One drill 4.2 mm (1500 rpm) for conical IDAll implant, Implants Diffusion International (Montreuil, France). The length was 12 mm.

For each group, 20 perforations were made without and with irrigation, using a new drill for each situation. The perforations without irrigation were used as control of the process used in this study. The time needed to complete the drilling was recorded.

For this experiment, three synthetic bone blocks of type I density (Nacional Ossos, São Paulo, Brazil), with a thickness of 40 mm, a width of 130 mm, and a length of 180 mm, were used. Foam is available in a range of sizes and densities; in this study, it was 0.64 g/cm^3 (40 pcf = 40 pounds per cubic foot).

For the temperature measurements, a type K thermocouple device (Mod. TP-01, Lutron Electronics Co., Inc., Coopersburg, PA, USA) was coupled to a digital thermometer (Lutron Electronics Co., Inc.) with a resolution of 0.1°C and installed into a hole (1 mm diameter and 2 mm in depth) placed 1 mm lateral to the perforations. This configuration is illustrated in Figure 1. After completion of one implant site preparation procedure, the subsequent was not performed until the temperature was returned to normalcy (19°C).

Parameters Evaluation and Statistical Analysis

Temperature was measured for each sample immediately before drilling (baseline value) and immediately after. For the multiple drilling samples, the measurements were performed after the last drilling step. Afterwards, the differences between the two measurements were computed. Mean values, confidence intervals (95% CI), and ranges were calculated for each group.

Shapiro–Wilk test was used to test normality of distributions of each group. The analysis of variance was used to evaluate differences among all groups. Student's unpaired *t*-test was applied to test differences between single and multiple drilling and between data obtained with or without irrigation. $P < .05$ was considered as the significance level.

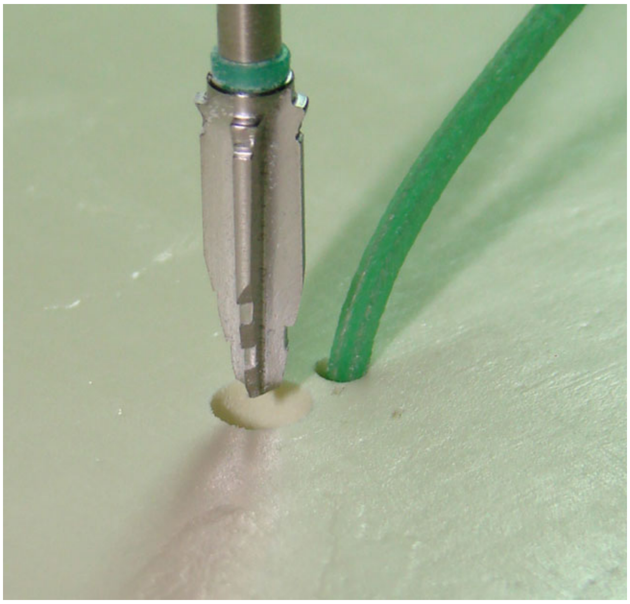

Figure 1 The thermocouple in position and the distance of the drilling.

RESULTS

The mean temperatures measured in the three groups and the mean differences with respect to baseline values (ΔT) with 95% CI considering the drilling without irrigation were: 25.54 ± 1.24°C (range: 22.2–27.9°C; $\Delta T = 6.67 \pm 1.17$; 95% CI: 6.16, 7.18) for Group 1; 28.11 ± 1.76°C (range: 26.4–32.1°C; $\Delta T = 8.70 \pm 1.63$; 95% CI: 7.98, 9.42) for Group 2; 26.48 ± 1.79°C (range: 23.3–30.3°C; $\Delta T = 7.83 \pm 1.77$; 95% CI: 7.05, 8.61) for Group 3. Considering the drilling with irrigation, the corresponding results were: 20.40 ± 1.17°C (range: 19.6–25.1°C; $\Delta T = 1.84 \pm 1.28$; 95% CI: 1.28, 2.40) for Group 1; 22.21 ± 1.38°C (range: 20.7–26.8°C; $\Delta T = 3.07 \pm 1.42$; 95% CI: 2.44, 3.69) for Group 2; while it was 20.25 ± 0.82°C (range: 18.9–22.3°C; $\Delta T = 1.73 \pm 0.95$; 95% CI: 1.31, 2.15) for Group 3.

Considering absolute values, Group 1 and Group 3 yielded similar results (not significantly different) in all experimental conditions. In Group 2, significantly higher temperatures were recorded with respect to the other two groups both with and without irrigation (Figures 2 and 3). Figures 4 and 5 show the graph with averages, quartiles, maximum and minimum values of the analyzed groups. No significant difference was recorded for ΔT between Group 1 and Group 3 with irrigation (the experimental condition most similar to the clinical situation), while the ΔT for Group 2 was significantly higher than the other two groups.

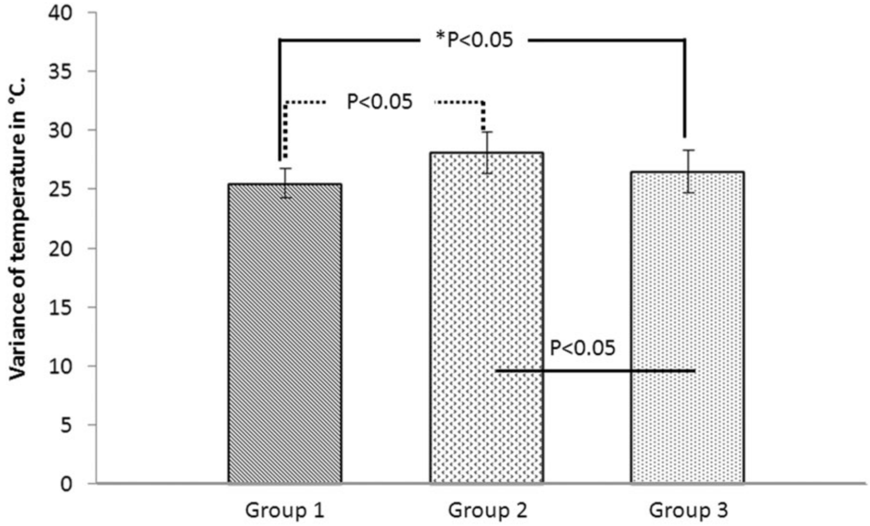

Figure 2 Bar graphs of the absolute values and statistical comparisons between groups without irrigation (*no significant difference).

The time for drilling was on the average 10 seconds for Group 3 and 80 seconds for Groups 1 and 2 (including three consecutive drilling steps plus the time for changing the drills). The time needed to return to baseline temperature after each implant site preparation procedure was approximately 5 to 10 minutes.

DISCUSSION

In the present study, a single drilling step was compared with conventional multiple drilling sequence regarding heat generation during the preparation of implant sites.

The results demonstrated that the use of a bur specially developed for preparing the implant site through a simplified drilling phase did not generate more heat in the bone surrounding the implant site than the conventional multiple sequence of burs for drilling. This might be a possible explanation for the excellent clinical results recently presented (98% of implant survival) in the evaluation of 350 implants installed with the use of a single drill in several clinical procedures.[26]

This consideration might be relevant to suggesting a standardized method for preparing implant site because it is derived from an investigation conducted with an experimental mechanical device, adequately programmed and standardized. Some authors have previously performed experimental osteotomies with

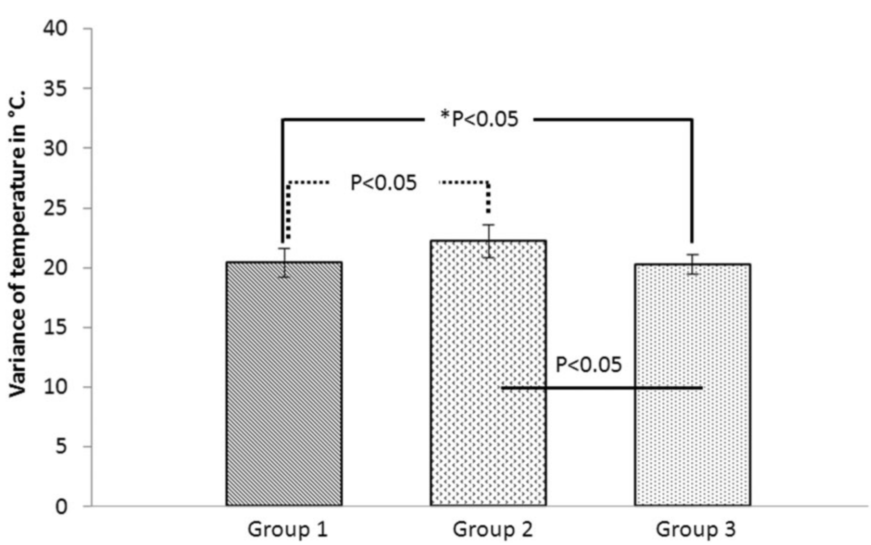

Figure 3 Bar graphs of the absolute values and statistical comparisons between groups with irrigation (*no significant difference).

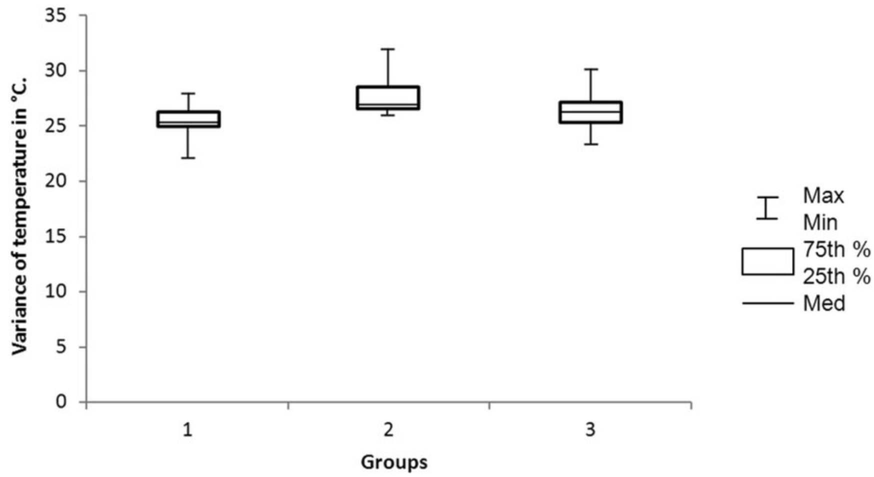

Figure 4 Variation of temperature in the groups without irrigation.

different protocols, such as a saw blade and only external irrigation, in samples of blocks of bovine mandible, in vitro and in vivo.[29–31] Ercoli and colleagues performed osteotomies in samples of bovine ribs in vitro, comparing seven brands of drills, with only external irrigation.[29] In the present study, only external irrigation was adopted.

Considering the effect of drill design on heat generation in cortical bone, many aspects were highlighted as important to reduce the physical stress. Drill design should allow for the less traumatic surgery as possible, and this consideration should determine drill characteristics as flute geometry and design, sharpness of the cutting tool, diameter, as well as drilling protocol features such as drilling speed, axial force (pressure applied to the drill), bur angulation, irrigation, torque and thrust forces, use of multiple burs with incremental diameter versus one-step drilling.[17,32] Also, bone characteristics, like cortical bone thickness and bone density, as well as the time needed for implant site preparation, may affect heat generation during drilling.

In this study, the Implant Diffusion International (IDI; Montreuil, France) drills were used at higher rotation speed as compared with the final drills of the other two systems. It has been suggested that high rotation speed in combination with a large applied force allows a faster site preparation and a minimum increase of temperature as compared with lower rotation speed and pressure.[33,34] In the present experimental protocol, the pressure applied to the drill was the same for all the three groups, but with the IDI drills the site preparation was completed within 10 seconds, while with the two

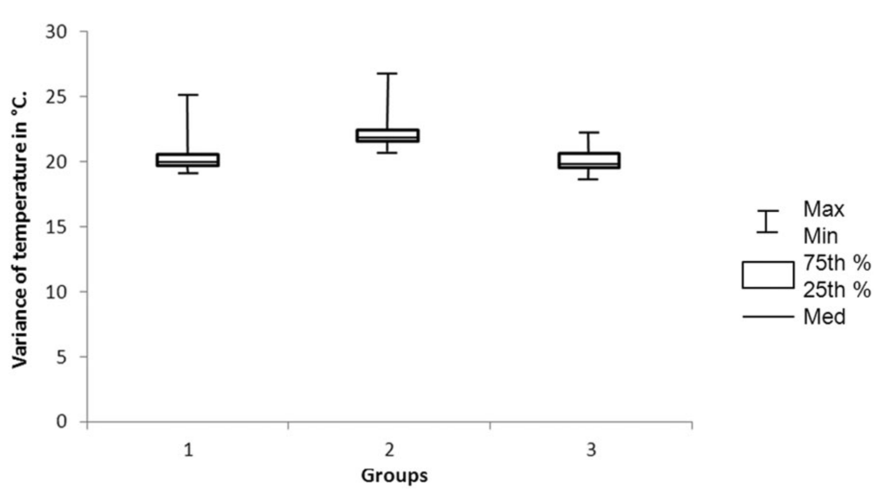

Figure 5 Variation of temperature in the groups with irrigation.

other system the procedures took significantly longer. However, the time needed for drilling in Groups 1 and 2 might be considered faster as compared with the clinical situation. While this may have caused a slight overestimation of the temperature due to a reduced recovery between consecutive drilling steps, this allowed for a rigorous standardization of the protocol. The possibility of shortening the overall drilling procedure may prove beneficial to tissues reducing the local damage as well as the patients' discomfort. In fact, prolonged tissue exposure may be detrimental to the postoperative course due to the increased release of pro-inflammatory cytokines and consequent amplified inflammatory response.[35]

The time required to return to baseline temperature (5–10 minutes) may seem quite large. This could be related to the bone heat dissipation properties which are hypothetically low in the cortical bone blocks used in this in vitro study, but should be far greater in the in vivo situation due to the bone vascularization system, which largely contributes to heat dissipation.

In the present study, different drill designs and systems were compared. The results suggested that a simplified drilling system generated similar heat to the cortical bone than using a conventional drilling. When compared in vivo, histologically, Jimbo and colleagues suggested that bone response to the implants installed with a simplified protocol is comparable with the conventional drilling protocol.[36]

Even though this consideration may appear obvious, the entity of the difference between the two systems is relevant and cannot be disregarded, aiming to reduce the heat generation as much as possible.

Though some authors declared that studies about comparisons between different cooling systems provided insufficient data for definitive conclusions,[32] many published studies investigated different systems aiming at reducing heat generation in the bone tissue while drilling.

Benington and colleagues, in 1996 and in 2002, described that an external irrigation system can significantly reduce heat generation during drilling procedure.[20,37] In the present study, the use of irrigation allowed for decreasing bone temperature by 5 to 6°C as compared with drilling procedures performed without irrigation in all groups.

Sener and colleagues, in 2009, evaluated the difference in temperature at various depths while preparing implant site with an external irrigation device, describing that the majority of heat was generated in the superficial part of the cavity, due to the characteristics of compact bone.[11] This issue can justify the position of thermocouples in our experimental model, which were placed within the superficial 2 mm of the bone samples.

Another study compared different shapes of surgical drills with external irrigation, suggesting that conical drills allowed for a lower heat generation if irrigated with an external device while drilling.[18]

One study of Carvalho and colleagues, in 2011, pointed out that the use of abundant irrigation was able to reduce the impact of drill design or drilling methods on heat generation.[19] In fact, it was observed that during the whole in vitro experiment, the measured temperature never approached a level (47°C) that can cause an irreversible damage to the bone. This observation was confirmed also in our study, where the results of temperature measurements were always lower than the previously cited threshold value.

Augustin and colleagues, in 2012, examined the performances of a drill with an internal irrigation system in terms of heat generation.[38] Even though it was observed that an increase in drill diameter resulted in an increase of heat generation, the measured temperature never overcome the critical 47°C.

Other authors suggested that ceramic drills can produce less heat while drilling than steel drills, further highlighting the importance of drill material and characteristics in heat generation.[7] As far as we know, no published study has ever compared a single drilling protocol versus conventional multiple incremental drilling systems.

Even though the findings of the present work are statistically significant, several limitations emerged. First, sample size is relatively small, as well as the number of drillings even though the use of standardized experimental design can increase the external validity of the results. Then, a surgical guide was used and this was shown to influence the temperature measured at the cortical bone level. The blocks of synthetic bone used in the present study have been specifically designed to reproduce the physical properties of the cortical bone in terms of hardness, density, elasticity (Young's modulus). The physical features of these synthetic bone blocks are homogeneous throughout their volume, so as to obtain a good standardization of the procedures and avoid introducing possible sources of bias in the measurements. However, due to natural inhomogeneities in the human jawbones, there might be differences between such model and the in vivo situation. Finally, only blocks of bone type 1 were used, which is not so common in clinical situations. This was done because such type of bone is at greater risk for developing excessive heating during drilling, as compared with softer bone type, and we aimed at testing the most risky situation.

Furthermore, we found that the baseline temperature for Group 2 was significantly greater than the other two groups, whose baseline values were similar. The latter issue, however, was overcome by using the temperature difference for the comparisons instead of the absolute values, thereby disregarding any inhomogeneity among baseline values.

Group 2 also displayed the highest temperature difference among the investigated drilling systems. This may have been caused by peculiar features of the drills or the protocol recommended by the manufacturer, though the magnitude of the bone heating under irrigation is still small, like the other two drilling systems, and should allow for a safe drilling in the clinical situation.

In the translation to clinical reality, it must also be acknowledged that the single drilling step procedure has some limitations. In fact, with the multiple-step drilling technique it is possible to modify the axis appropriately, in case the first drills have created a misaligned implant site. Therefore, through correction of the drilling axis of the larger burs, the final implant site can match the original project of the treatment plan. By reducing the number of steps, down to a single drilling phase, a far greater precision is needed as it is not feasible to correct misalignments. Hence, it may be advisable to adopt a surgical template to drive the bur properly, at least during the very first procedures, because a learning curve is necessary even for the experienced surgeon. Further studies should be performed to investigate the precision of single drilling as compared with multiple incremental drilling protocol in creating a proper implant site.

CONCLUSION

The present study showed that a single bur system did not generate more heat than a conventional drilling sequence while preparing implant site, and may be considered as safe as the latter. Moreover, the use of drills with irrigation is effective in reducing the heat generation at the cortical bone level. More studies, both in vitro (possibly on human bone samples) and in vivo, will help to achieve a better understanding of heat generation phenomenon during the preparation of implant sites, as well as to establish the ideal drilling protocol for different bone types.

REFERENCES

1. Eriksson RA, Albrektsson T, Magnusson B. Assessment of bone viability after heat trauma. A histological, histochemical and vital microscopic study in the rabbit. Scand J Plast Reconstr Surg 1984; 18:261–268.
2. Lundskog J. Heat and bone tissue. An experimental investigation of the thermal properties of bone and threshold levels for thermal injury. Scand J Plast Reconstr Surg 1972; 9:1–80.
3. Leunig M, Hertel R. Thermal necrosis after tibial reaming for intramedullary nail fixation. A report of three cases. J Bone Joint Surg Br 1996; 78:584–587.
4. Brisman DL. The effect of speed, pressure, and time on bone temperature during the drilling of implant sites. Int J Oral Maxillofac Implants 1996; 11:35–37.
5. Kerawala CJ, Martin IC, Allan W, Williams ED. The effects of operator technique and bur design on temperature during osseous preparation for osteosynthesis self-tapping screws. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1999; 88:145–150.
6. Harris BH, Kohles SS. Effects of mechanical and thermal fatigue on dental drill performance. Int J Oral Maxillofac Implants 2001; 16:819–826.
7. Oliveira N, Alaejos-Algarra F, Mareque-Bueno J, Ferrés-Padró E, Hernández-Alfaro F. 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 2012; 23:963–969.
8. Albrektsson T, Brånemark PI, Hansson HA, Lindström J. Osseointegrated titanium implants. Requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. Acta Orthop Scand 1981; 52:155–170.
9. Albrektsson T, Brunski J, Wennerberg A. "A requiem for the periodontal ligament" revisited. Int J Prosthodont 2009; 22:120–122.
10. Esposito M, Hirsch JM, Lekholm U, Thomsen P. Biological factors contributing to failures of osseointegrated oral implants: (II). Etiopathogenesis. Eur J Oral Sci 1998; 106: 721–764.
11. Sener BC, Dergin G, Gursoy B, Kelesoglu E, Slih I. Effects of irrigation temperature on heat control in vitro at different drilling depths. Clin Oral Implants Res 2009; 20:294–298.
12. Eriksson A, Albrektsson T, Grane B, McQueen D. Thermal injury to bone. A vital-microscopic description of heat effects. Int J Oral Surg 1982; 11:115–121.
13. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: a vital-microscopic study in the rabbit. J Prosthet Dent 1983; 50:101–107.

14. Eriksson RA, Adell R. Temperatures during drilling for the placement of implants using the osseointegration technique. J Oral Maxillofac Surg 1986; 44:4–7.
15. Chacon GE, Bower DL, Larsen PE, McGlumphy EA, Beck FM. Heat production by 3 implant drill systems after repeated drilling and sterilization. J Oral Maxillofac Surg 2006; 64:265–269.
16. Sumer M, Misir AF, Telcioglu NT, Guler AU, Yenisey M. Comparison of heat generation during implant drilling using stainless steel and ceramic drills. J Oral Maxillofac Surg 2011; 69:1350–1354.
17. Oh HJ, Wikesjo UM, Kang HS, Ku Y, Eom TG, Koo KT. Effect of implant drill characteristics on heat generation in osteotomy sites: a pilot study. Clin Oral Implants Res 2011; 22:722–726.
18. Scarano A, Piattelli A, Assenza B, et al. Infrared thermographic evaluation of temperature modifications induced during implant site preparation with cylindrical versus conical drills. Clin Implant Dent Relat Res 2011; 13:319–323.
19. Carvalho AC, Queiroz TP, Okamoto R, Margonar R, Garcia IR, Jr, Magro Filho O. 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 2011; 26:1193–1201.
20. Benington IC, Biagioni PA, Briggs J, Sheridan S, Lamey PJ. Thermal changes observed at implant sites during internal and external irrigation. Clin Oral Implants Res 2002; 13: 293–297.
21. Gehrke SA, Neto HL, Mardegan FE. Investigation of the effect of movement and irrigation systems on temperature in the conventional drilling of cortical bone. Br J Oral Maxillofac Surg 2013. DOI: 10.1016/j.bjoms.2012.10.023.
22. Augustin G, Davila S, Udiljak T, Vedrina DS, Bagatin D. Determination of spatial distribution of increase in bone temperature during drilling by infrared thermography: preliminary report. Arch Orthop Trauma Surg 2009; 129: 703–709.
23. Lavelle C, Wedgwood D. Effect of internal irrigation on frictional heat generated from bone drilling. J Oral Surg 1980; 38:499–503.
24. Misir AF, Sumer M, Yenisey M, Ergioglu E. Effect of surgical drill guide on heat generated from implant drilling. J Oral Maxillofac Surg 2009; 67:2663–2668.
25. Sharawy M, Misch CE, Weller N, Tehemar S. Heat generation during implant drilling: the significance of motor speed. J Oral Maxillofac Surg 2002; 60:1160–1169.
26. Bettach R, Taschieri S, Boukhris G, Del Fabbro M. Implant survival after preparation of the implant site using a single bur: a case series. Clin Implant Dent Relat Res 2013. DOI: 10.1111/cid.12082.
27. Basic Information on the Surgical Procedures. 2012. Straumann® Dental Implant System. http://www.straumann.com. (Accessed February 2013).
28. Nobel Replace® and Replace Select™ Tapered: Procedures Manual. 2012. http://www.nobelbiocare.com. (Accessed February 2013).
29. Ercoli C, Funkenbusch PD, Lee HJ, Moss ME, Graser GN. 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 2004; 19:335–349.
30. Wachter R, Stoll P. Increase of temperature during osteotomy. In vitro and in vivo investigations. Int J Oral Maxillofac Surg 1991; 20:245–249.
31. Sutter F, Krekeler G, Schwammberger AE, Sutter FJ. Atraumatic surgical technique and implant bed preparation. Quintessence Int 1992; 23:811–816.
32. Augustin G, Zigman T, Davila S, et al. Cortical bone drilling and thermal osteonecrosis. Clin Biomech (Bristol, Avon) 2012; 27:313–325.
33. Abouzgia MB, James DF. Measurements of shaft speed while drilling through bone. J Oral Maxillofac Surg 1995; 53:1308–1316.
34. Abouzgia MB, Symington JM. Effect of drill speed on bone temperature. Int J Oral Maxillofac Surg 1996; 25:394–399.
35. Penarrocha M, Garcia B, Marti E, Balaguer J. Pain and inflammation after periapical surgery in 60 patients. J Oral Maxillofac Surg 2006; 64:429–433.
36. Jimbo R, Giro G, Marin C, et al. Simplified drilling technique does not decrease dental implant osseointegration: a preliminary report. J Periodontol 2012. DOI: 10.1902/jop.2012.120565.
37. Benington IC, Biagioni PA, Crossey PJ, Hussey DL, Sheridan S, Lamey PJ. Temperature changes in bovine mandibular bone during implant site preparation: an assessment using infra-red thermography. J Dent 1996; 24:263–267.
38. Augustin G, Davila S, Udilljak T, Staroveski T, Brezak D, Babic S. Temperature changes during cortical bone drilling with a newly designed step drill and an internally cooled drill. Int Orthop 2012; 36:1449–1456.