



Effect of surgical drill guide and irrigants temperature on thermal bone changes during drilling implant sites – Thermographic analysis on bovine ribs

Uticaj hirurškog stenta i temperature irigansa na termičke promene u kosti tokom preparacije ležišta implantata – termografska analiza na goveđim rebrima

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Abstract

Background/Aim. During drilling implant sites, mechanical energy is converted into thermal one resulting in transient rise in temperature of surrounding bone. The temperature of 47°C exceeding one minute impairs osseointegration, compromises mechanical properties of the local bone and could cause early implant failure. This *in vitro* study aimed to assess the effect of surgical drill guide and temperature of irrigants on thermal changes of the local bone during drilling implant sites, and to test the influence of irrigants temperature on the temperature of surgical drill guide. **Methods.** A total of 48 specimens obtained from bovine ribs were randomly allocated to four experimental conditions according to the 2 × 2 factorial design: drill guide (with or without) and saline (at 25°C or 5°C). Real-time infrared thermography was used as a method for temperature measurement. The primary outcome was bone temperature change during drilling implant sites measured at 3 osteotomy depths, whereas the second one was change in the temperature

of the drill guide. Data were analyzed by Brunner and Langer nonparametric analysis and Wilcoxon test. **Results.** The effect of drill guide on the changes of bone temperature was significant at the entrance of osteotomy, whereas the effect of saline temperature was significant at all osteotomy levels ($p < 0.001$). No significant interaction was found ($p > 0.05$). Guided surgery and irrigation with saline at 25°C were associated with the highest bone temperature increase. Increase in drill guide temperature was significantly higher when saline at 25°C was used ($p < 0.001$). **Conclusion.** Guided implant site preparation generates higher temperature of the local bone than conventional drilling, not exceeding the threshold for thermal bone necrosis. Although saline at room temperature provides sufficient heat control during drilling, cooled saline is more effective regardless the use of surgical drill guide.

Key words: dental implants; irrigation; temperature; bone and bones; stents.

Apstrakt

Uvod/Cilj. Tokom preparacije ležišta za implantat mehanička energija pretvara se u toplotnu, što dovodi do prolaznog povišenja temperature okolne kosti. Temperatura od 47°C tokom više od jednog minuta narušava oseointegraciju, mehaničke osobine lokalne kosti i može dovesti do ranog neuspeha implantata. Cilj ove *in vitro* studije bio je da se ispita uticaj hirurškog stenta i temperature irigansa na termičke promene u kosti tokom preparacije ležišta za implantat, kao i uticaj temperature irigansa na tempera-

turu hirurškog stenta. **Metode.** Ukupno 48 uzoraka dobijenih od goveđih rebara bilo je podeljeno metodom slučajnog izbora u četiri grupe prema 2 × 2 faktorskom dizajnu: prisustvo hirurškog stenta (da/ne) i temperatura fiziološkog rastvora (25°C/5°C). Temperatura je merena infracrvenom termografijom u realnom vremenu. Primarni ishod bio je promena temperature kosti tokom preparacije ležišta implantata merena na tri dubine ležišta, a sekundarni ishod promena temperature hirurškog stenta. Podaci su analizirani Bruner-Langer neparametrijskom analizom i Wilkersonovim testom. **Rezultati.** Uticaj hirurškog stenta na promenu

temperature kosti bio je značajan na ulazu u ležište za implantat, dok je uticaj temperature irigansa bio značajan na svim dubinama ležišta ($p < 0,001$). Međusobni uticaj ispitivanih faktora nije bio značajan ($p > 0,05$). Upotreba hirurškog stenta i ispiranje fiziološkim rastvorom temperature 25°C bili su praćeni najvišim porastom temperature kosti. Porast temperature hirurškog stenta bio je značajno viši kada je korišćeno ispiranje na temperaturi od 25°C ($p < 0,001$). **Zaključak.** Tokom kontrolisane preparacije ležišta za implantat došlo je do većeg zagrevanja kosti u porede-

nju sa standardnom preparacijom, ne premašujući temperaturu kritičnu za termičku nekrozu kosti. Iako ispiranje na sobnoj temperaturi obezbeđuje dovoljno hlađenja kosti tokom preparacije ležišta za implantat, ohlađeni rastvor za ispiranje je efikasniji bez obzira na primenu hirurškog stenta.

Ključne reči:
implanti, stomatološki; lavaža; temperatura; kost; stentovi.

Introduction

During drilling implant sites, mechanical work energy is converted into thermal resulting in transient rise in temperature of the surrounding bone¹. The response of bone tissue to the generated heat depends on the temperature achieved and time of exposure². The temperature of 47°C exceeding 1 minute impairs osseointegration, compromises mechanical properties of the local bone and therefore, it is considered to be a factor of early implant failure³⁻⁶.

The use of surgical drill guides increases the accuracy of implant placement in a required 3D position and reduces the surgical error; however, it generates higher local bone temperature than conventional drilling⁷⁻¹¹. Bone temperature increase is particularly emphasized when guided surgery for dental implants is associated with flapless approach or reused drills^{9,10}.

Irrigation of the bone-drill interface with sterile saline is a central strategy in the prevention of bone overheating during drilling implant sites¹². It eliminates heated bone chips from the osteotomy and reduces friction during drilling, thus contributing to decreased generation of the frictional heat¹³. Saline at room temperature can provide sufficient cooling during conventional drilling, although in dense cortical bone or at high rotational speed deleterious bone temperatures might be generated¹⁴. Cooled saline is proved to be more effective when drilling without the surgical guide¹⁵.

The effect of saline temperature on heat control in guided surgery is unknown. Inability of direct irrigation of the active drill tip together with friction between metal sleeve and drill periphery seems to contribute to great heat generation expected when drill guide is used. It might be hypothesized that cooled irrigants would reduce conduction of frictional heat generated at the drill-sleeve interface to the adjacent bone more than irrigants at room temperature and therefore lower bone temperature increase could be expected. The aim of this *in vitro* study was to assess the effect of surgical drill guide and temperature of irrigants on thermal changes of the local bone during drilling implant sites, and to test the influence of irrigants temperature on the temperature of surgical drill guide.

Methods

This *in vitro* study was performed at the Faculty of Dentistry, University of Belgrade, Serbia in June and July 2014 after receiving permission from the authorized Ethical Committee (No. 36/9).

Bone specimens

Bovine ribs, obtained from male animals 9 months old and 180 kg weight, were used to simulate human jaw bone. All specimens were collected from the local butcher shop and were of already slaughtered animals. Samples with the same thickness (2 mm) of cortical bone and overall height of at least 15 mm were selected to provide uniform experimental conditions¹⁶. The residual soft tissue was removed and bovine ribs were cut into 25 mm length blocks that were numbered. A total of 48 specimens were obtained from 4 bovine ribs. Two factors, each with 2 levels, were tested in this experiment: surgical drill guide (with or without) and saline temperature (at room temperature of 25°C or cooled at 5°C). Each rib was divided into 3 parts and each part was cut into 4 specimens which were randomly assigned to 1 of 4 experimental conditions using computer generated random numbers. For 24 specimens that simulated guided surgical approach, surgical drill guides were made. Impression of bone specimen was taken using silicone material and plaster cast was prepared. It was coated by 2 mm layer of red wax that simulated soft tissue. Surgical drill guide was made from the self-curing acrylic material designed for surgical templates (3D-resin, Bredent, Senden, Germany). This material was adopted over the wax layer and inner sleeve with diameter of 2.39 mm (SKYplanX drill sleeve, Bredent, Senden, Germany) was locked into outer guiding sleeve and together were embedded into a guide, at a constant distance of 5 mm from the bone specimen periphery as measured by the calliper (Figure 1). The remaining 24 control specimens were covered by only 2 mm thick layer of red wax to simulate soft tissue in flapless surgical approach. To maintain the thermophysical properties, specimens not used within few hours were prepared according to the guidelines established by Sedlin and Hirsch¹⁷, i.e. the specimens were kept moist in saline solution and stored at 10°C.

Temperature measurement system

Real-time infrared thermography was used as a method of bone temperature measurement. Bone temperature was measured by the infrared thermographic camera Varioscanner R high resolution 3021 (Jenoptik, Dresden, Germany) (Figure 2). It detected infrared radiation from the surface of the bone that was directed by the lens system toward the photo-sensor where its energy was transformed into electrical impulses that provided visualization of bone temperature values on the



Fig. 1 – Bone specimen – cross-sectional view of the specimen simulating guided surgery.



Fig. 2 – Experimental set-up – cross-sectional specimen's surface exposed to infrared camera.

display as a range of colours. The thermal resolution of camera was $\pm 0.03^{\circ}\text{C}$, temperature range from -40°C to $1,200^{\circ}\text{C}$ and spectral range $8\text{--}12\ \mu\text{m}$. The range of temperatures on the thermogram was shown as a band with different shades of different colours. The obtained thermograms were processed by IRIBIS software¹⁸ (Figure 3).

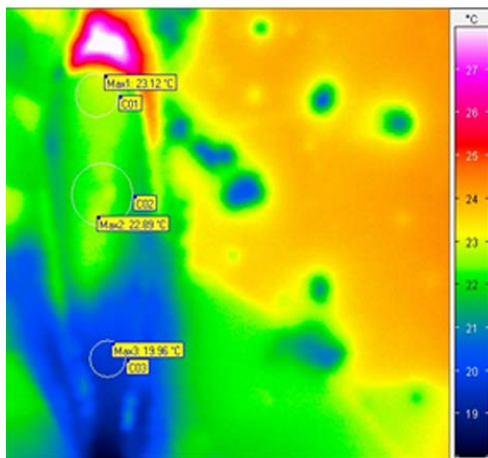


Fig. 3 – Thermogram processed by IRIBIS software. The range of temperatures on thermogram shown as a band with different shades of different colours.

Experimental protocol

All measurements were realized at the cross-sectional area of the specimen, 5 mm away from the drill sleeve. This surface of specimen was covered with a layer of graphite spray of 0.95 emissivity in order to annul the difference between the cortical and spongy bone layers. Each prepared specimen was fixed in a clamp with cross-sectional surface exposed to infrared camera that was at a distance of 0.8 m (Figure 2). The surface that was used for the measurement was isolated from the irrigans by cofferdam since a fluid might mask the real temperature readings. A bottle of saline

was kept during the entire experiment in the thermostable bag to maintain the temperature of the solution. Cardboard shield was used to eliminate the background thermal radiation. All measurements were performed in the same, controlled environmental conditions with a temperature of the operating room between 22°C and 24°C .

In order to eliminate variability in operator-related factors affecting bone temperature during drilling, particularly the applied hand pressure, the same operator performed all the drillings. Conventional dental handpiece (W&H, Burmoos, Austria) was used. Temperature was measured during implant site preparation by pilot drill, designed for computer guided implantology, with the diameter of 2.35 mm and intraosseous length of 13 mm (SKYplanX, Bredent, Senden, Germany). Drill was inserted through corresponding metal sleeve in an intermittent fashion under copious irrigation with saline at the flow rate of 50 mL/min. Excessive saline was aspirated near the site of preparation. The temperature of the saline was adjusted to the experimental condition. The drill speed was 600 rpm. The same drilling parameters were used for osteotomies in the control specimens (conventional drilling).

Temperature measurement started prior to drilling (baseline) and continued up to osteotomy completion. Bone temperature was measured along the entire length of the implant site – especially during drilling at 3 site levels: entrance, middle and bottom. The primary study outcome was bone thermal change counted by subtracting the baseline value from the maximum value recorded during drilling and was calculated for all 3 implant site levels. The secondary study outcome was change in the temperature of the drill guide calculated as the difference between the maximum value recorded during drilling and the baseline value. The outcome assessor was blind to the temperature of the saline but not to the surgical approach (guided or conventional) since the outline of the stent could be visualized on thermograms. Statistician was completely blind to the allocation of the intervention.

Statistical analysis

Data were analyzed in R statistical software (The R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics was performed with a measure of central tendency (mean and median) and measure of dispersion (min, max, standard deviation). The normality of data distribution was checked by 1-sample Kolmogorov–Smirnov test.

Effects of surgical drill guide (with vs without), temperature of the saline (at room temperature of 25°C vs cooled at 5°C) and their interaction on the changes in the temperature of the local bone were assessed by Brunner and Langer non-parametric analysis of longitudinal data. One analysis for each osteotomy level was carried out. Two-sided *p*-values < 0.05 were considered as statistically significant.

The difference in changes of the temperature of the surgical drill guide during drilling with saline at room temperature of 25°C versus cooled saline at 5°C as irrigants was analysed by Exact Wilcoxon signed rank test for paired samples and previously the Cabilio-Masaro test of symmetry was run. One-sided *p*-value < 0.05 was considered as statistically significant.

A correlation between the temperature of the surgical drill guide and the temperature of bone at the implant site entrance was tested by Spearman's rank correlation coefficient.

Results

All the temperature increases recorded in this study were in the physiological range (Table 1, Figure 4). The maximal temperature increase was 7.48°C and it was recorded in one specimen at the entrance of the prepared implant site when surgical drill guide was used together with saline at room temperature. The mean increase in bone temperature was decreasing with increasing depth of the site for all experimental conditions except when conventional drilling was used under cooled saline (Figure 4).

At the entrance of the preparation, the use of surgical drill guide had a significant impact on thermal changes of the adjacent bone (ANOVA-Type Statistic = 30.952; *df* = 1; *p* < 0.001). Higher bone temperature increases were found when surgical drill guide was used compared to conventional drilling (Figure 4, Table 1). The effect of the saline temperature on bone heating was also significant (ANOVA -Type Statistic = 85.576; *df* = 1; *p* < 0.001) at this surgical site level, whereas the effect of interaction between the use of surgical drill guide and saline temperature was not significant (ANOVA-Type Statistic = 0.955; *df* = 1; *p* = 0.328). Irrigation of the surgical site with cooled saline reduced the increase of bone temperature regardless the use of drill guide. When cooled saline was used without drill guide, the values of bo-

Table 1
Descriptive statistics of bone thermal changes (°C) during drilling implant sites with regards to the experimental condition

Site depth	Experimental condition	\bar{x}	SD	Median	Min	Max
Entrance	drill guide + saline at 25°C	3.54	1.87	2.86	1.69	7.48
	no drill guide + saline at 25°C	1.24	0.68	1.44	0.18	2.24
	drill guide + saline at 5°C	0.59	1.32	0.3	-1.87	2.44
	no drill guide + saline at 5°C	-0.37	0.42	-0.30	-1.21	0.31
Middle	drill guide + saline at 25°C	1.73	1.04	1.62	0.02	3.41
	no drill guide + saline at 25°C	1.10	1.16	0.67	0.04	3.40
	drill guide + saline at 5°C	0.16	0.77	-0.03	-0.86	2.05
	no drill guide + saline at 5°C	-0.12	0.36	-0.11	-0.86	0.68
Bottom	drill guide + saline at 25°C	0.95	1.77	0.37	0.00	6.37
	no drill guide + saline at 25°C	0.92	1.19	0.50	0.02	4.46
	drill guide + saline at 5°C	0.25	0.88	-0.01	-0.51	2.28
	no drill guide + saline at 5°C	0.14	1.09	-0.12	-0.69	3.54

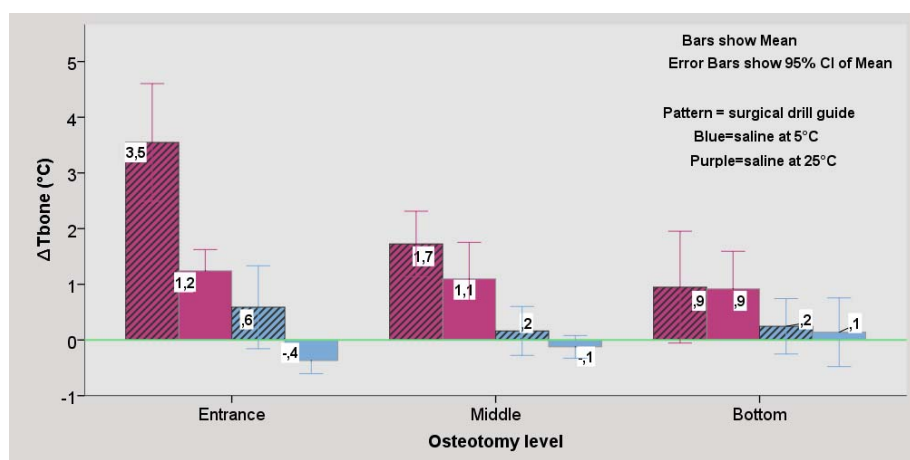


Fig. 4 – Bone thermal changes during drilling implant sites with regard to the use of surgical drill guide and saline temperature.

ne temperature recorded during drilling were lower than baseline values, *ie* a decrease of bone temperature was observed (Figure 4, Table 1).

The effect of the saline temperature on bone heating remained significant at the middle osteotomy depth (ANOVA-Type Statistic = 36.814; $df = 1$; $p < 0.001$) whereas the effect of the surgical drill guide (ANOVA-Type Statistic = 3.637; $df = 1$; $p = 0.056$), or their interaction (ANOVA-Type Statistic = 0.108; $df = 1$; $p = 0.742$) were not. Lower bone temperature increase was recorded when irrigation was performed with cooled saline. When conventional drilling was performed under cooled saline, even a decrease of bone temperature comparing to baseline values was observed (Figure 4, Table 1).

Bone thermal changes at the bottom of the surgical site were significantly affected by temperature of the saline used as an irrigans (ANOVA-Type Statistic = 26.064; $df = 1$; $p < 0.001$), whereas surgical drill guide had no significant influence (ANOVA-Type Sta-

tistic = 0.072; $df = 1$; $p = 0.787$) neither the interaction (ANOVA-Type Statistic = 1.080; $df = 1$; $p = 0.298$). At this site level, bone temperature increased during drilling under all experimental conditions with the mean increase below 1°C. Lower bone temperature increase was recorded when cooled saline was used compared to saline at room temperature (Figure 4, Table 1).

The median of changes in surgical drill guide temperature during drilling was significantly higher when irrigation was performed with saline at room temperature of 25°C compared to the cooled saline at 5°C ($p < 0.001$; 95% CI for the median difference: 2.785–7.185) (Figure 5 and Table 2).

A correlation between temperature of the surgical drill guide and temperature of the bone at the surgical site entrance was significant, positive and high (Spearman $\rho = 0.868$; $p = 0 < 001$). A higher increase in temperature of the surgical drill guide was associated with higher heating of the adjacent bone (Figure 6).

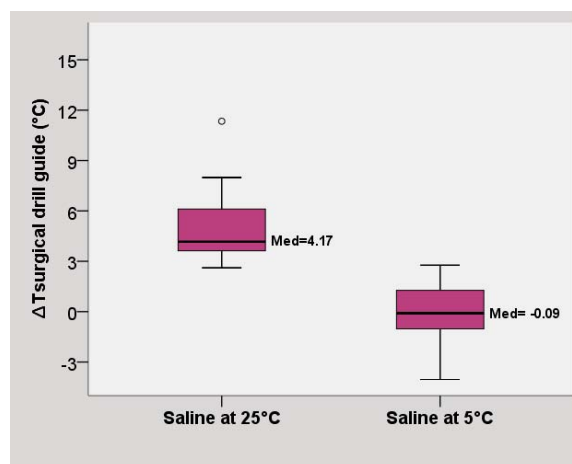


Fig. 5 – Box-plots showing changes of the temperature of drill guide as a function of saline temperature. Data were presented as the median (horizontal line), with the box representing the 75th centiles and whiskers representing the statistical range. Circle was an outlier.

Table 2
Descriptive statistics of temperature changes of surgical drill guide (°C) during drilling implant sites with regard to the temperature of the saline used as an irrigans

Experimental condition	\bar{x}	SD	Median	Min	Max
Saline at 25°C	5.07	2.56	4.17	2.61	11.34
Saline at 5°C	0.02	1.91	-0.09	-4.04	2.77

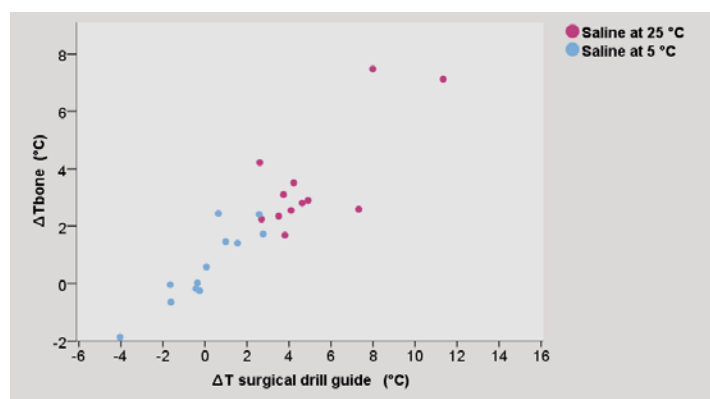


Fig. 6 – Correlation between surgical drill guide temperature and bone temperature at the surgical site entrance.

Discussion

The results of our study indicate higher heat generation during implant site preparation through guided surgical approach compared to conventional drilling. However, neither surgical technique exceeded temperature values critical for thermal bone necrosis. This is in line with data reported in several *in vitro* studies utilizing various bone models and methods of temperature measurement⁸⁻¹¹. The effect of drill guide use was significant only at the superficial level of the bony walls of the prepared site. This level of the site is susceptible to higher warming than deeper parts due to prolonged exposure to friction forces and higher coefficient of friction of cortical bone layer². Therefore, cortical bone at the implant site entrance requires the most intensive cooling. When no drill guide is used, the irrigants are routed directly to the drill tip where it penetrates the underlying tissues making effective control of heat generation. In the guided surgical approach, metal sleeves limit direct irrigation leading to a significant increase of the adjacent bone temperature. Further, heat generated from the friction of the metallic elements of the surgical drill guide could be conducted to the adjacent superficial bone layer, contributing to the increase of bone temperature. This is supported by a positive correlation between the temperature of the surgical drill guide and the temperature of bone at the site entrance found in our study. On the other hand, in the spongy bone layer of deeper parts of the surgical site, slight bone heating occurs that could be effectively controlled by the limited volume of saline directed through metallic sleeve in the drill guide. In contrast to our results, Misir et al.⁸ found significantly higher bone temperatures at all implant site depths when it was prepared by guided drilling compared to standard method of preparation. This discrepancy could be due to exclusively cortical model or high drilling speed used in their study.

Great bone heating associated with the guided surgical approach imposes the need for an effective method of heat control when this technique for implant site preparation is used. Internal irrigation seems beneficial in guided surgery, but its efficiency can be seriously hampered by clogged irrigation point, particularly when dense cortical bone is involved. Higher jaw bone temperatures have been documented *in vitro* when guided implant site drilling was performed with combined irrigation compared to external irrigation only⁸. A forced irrigation through the drill guide using room temperature irrigants at flow rate of 500 mL/min or greater could predictably prevent overheating of the bony walls of the implant site¹⁹. Regarding block of irrigants flow by metal sleeves as the main concern of guided drilling, it has been recommended to modify drill guide in a way to allow easier access of irrigants to the site of cortex penetration¹⁹. Our study singled out the use of cooled irrigants as another strategy for the control of the heat generated during drilling implants sites through guided approach. The obtained results indicate that saline at 5°C was more efficient in cooling bony walls of the prepared implant site at all its depths compared to room temperature saline (25°C), regardless the surgical

method used. When conventional drilling was used together with cooled saline, the temperature of the bone that surrounds superficial parts of the site was even decreasing to the level below the baseline values. Effective cooling of bone at deeper parts of the site when guided surgery is performed indicates that intermittent movements during drilling might compensate limited access of irrigants due to narrow space between the drill sleeve and drill itself.

According to our data, the use of irrigants cooled at 5°C during implant site drilling *via* the guided approach might be advantageous due to adequate control of adjacent bone temperature. However, when choosing a temperature of the irrigants in the clinical setting, the effect of cooled saline on nerves, vessels or other structures should also be considered²⁰. Histological data²¹ have shown higher osteoblast activity and greater increase in bone marrow dynamics when implant sites are drilled under saline at 4°C compared to 25°C. Rapid bone healing associated with the use of cooled saline has also been documented histomorphometrically, although irrigants temperature did not have any impact on the amount of newly formed bone²¹.

Our study has several limitations. Fluid movement and water rate might dissipate some heat during drilling, but infrared thermography, limited us to measure bone temperature in dry conditions since a fluid might mask the real temperature value impairing the accuracy of measurement²². The difference in thermal conductivity between bovine ribs and human jaw bone, as well as between the red wax and oral soft tissues presents another limitation of this study.

We employed the flapless approach to test the effects of surgical drill guide and irrigants temperature on bone thermal changes during drilling implant sites. It was chosen because in clinical settings guided drilling is usually associated with implant placement without raising a flap, the benefit of which is minimal invasiveness of the procedure. At the same time it is the worst scenario from the thermal point of view, because there is a double barrier to fluid flow: drill guide and underlying soft tissue. Migliorati et al.⁹ showed insignificant difference in temperature increase between flapless guided surgery and flap guided surgery. Bone temperature in our study was measured during drilling with the pilot drill, since its use is mandatory for guided surgery, whereas following drills, with increasing diameters, might be used after the removal of the drill guide. Also, it is expected that this drill generates the highest bone temperature increase during drilling due to small flutes that limit irrigation together with higher pressure of the drill tip on the adjacent tissue¹¹.

Conclusion

Guided implant site preparation generates higher temperature of local bone than conventional drilling, but not exceeding a threshold for thermal bone necrosis. Although saline at room temperature provides sufficient heat control during drilling, cooled saline was more effective regardless the use of surgical drill guide. The temperature of the surgical drill guide was reduced when cooled saline was used as an irrigant during drilling implant sites.

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