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Can a new cooling method be used in dental implant drilling? An in vitro pilot study

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Abstract

Aims: The aim of this in vitro pilot study was to evaluate the effectiveness of the CryoKB cooling method in increasing the heat-induced temperature during implant drilling in bovine femur bone and to determine its potential usefulness for future in vivo studies.

Methods: The study included four groups defined as follows: the G1 group, in which stainless steel materials were cooled using the CryoKB method (n=13); the G2 group, in which bone was cooled using the CryoKB method (n=13); the K1 group, in which stainless steel materials were cooled using an external irrigation solution (n=13); and the K2 group, in which bone was cooled using an external irrigation solution (n=13). The temperature was measured by creating a 5-mm-deep socket in the bone. The measurements were made every 5 minutes from 0 minutes to 1 hour, using a thermometer device with a type K probe.

Results: The temperature changes in 52 samples were evaluated. Statistically significant differences in temperature change were found between the G1 and G2 groups. Statistically significant differences in temperature were found between the G2 and K1 groups and between the G2 and K2 groups.

Conclusion: The newly developed cooling method provided more effective and long-lasting cooling than the traditional irrigation method.

Keywords: Bovine femur bone, external irrigation method, implant drill, traditional irrigation method

INTRODUCTION

Dental implants offer excellent treatment options to reduce the limitations of normal dentures, bridges, and missing teeth. However, for an implant to be placed in the jawbone, the implant socket must be prepared in the area with a sufficient amount of bone. The physiological state of establishing direct contact between the immobile implant placed in the implant socket and the bone has been defined as osseointegration.[1]

Many parameters must be considered for proper osseointegration to occur. If these parameters are not met, early implant failure can occur.[2] The causes of early implant failure are the development of postoperative infection, too high or too low torque, trauma that may cause implant mobility, improper early loading protocol, and heat-induced thermal necrosis during the preparation of the implant socket.[3,4]

Thermal necrosis is generally described as an undesirable condition characterized by the frictional heat generated during implant drilling, causing cellular destruction, matrix degeneration and enzymatic degradation.[5] As the spongiosis bone has richer cellular and vascular resources, it allows for better distribution of the heat generated by friction and has a higher regeneration capacity. In the cortical bone, the heat generated by friction inhibits regeneration.[6] In the literature, the recognized threshold temperature for regeneration is 44-47°C for 1 minute.[7]

Various techniques for temperature control during implant drilling have been described. External and internal cooling methods are used separately or in combination.[8] Laser thermometers, thermography and thermocouple can be used for temperature measurements.[9]

The CryoKB method involves the process of cooling the material in a freezer (at a temperature of –18 - –20°C controlled from the outside by a thermometer) without the use of any irrigation solution (Oztiryakiler Metalware Industry and Trade Joint Stock Company, Istanbul, Turkey).

In this pilot study, we aimed to compare cooling using an irrigation solution with cooling using the CryoKB method. We hypothesized that the CryoKB cooling method provides better and long-term cooling than the irrigation method.

METHODS

This study has been evaluated by the Animal Experiments Local Ethics Committee Presidency of Kırıkkale University Rectorate within the scope of diagnostic and therapeutic clinical applications, and it has been concluded that there is no need for an Ethics Committee decision. (Date: 08.06.2022, Decision No: E-100143). All procedures were carried out in accordance with the ethical rules and principles.

In the pilot study planned in vitro, four groups were formed as follows: the G1 group, in which stainless steel materials (Nucleoss, Sanlilar Medical Devices Medical Chemistry Industry Trade Limited Company, Izmir, Turkey) were cooled using the CryoKB method (n=13) and stored in the freezer at –18 - –20°C to cool the material; the G2 group, in which the bone was cooled using the CryoKB method (n=13) and stored in the freezer at –18 - –20°C to cool the material; the K1 group, in which the stainless steel materials were cooled using an external irrigation solution (Biofleks, OSEL Pharmaceutical Industry and Trade Joint Stock Company, Istanbul, Turkey; n=13), with continuous irrigation using saline at 28-31°C; and the K2 group, in which the bone was cooled using an external irrigation solution (n=13), with continuous irrigation using saline at 28 - 31°C.

Bovine femoral bone was used in the study. Care was taken to ensure that all bones were of type 1 density, defined as Hounsfield units greater than 1250 on cone-beam computed tomography. Non-vital bovine bone was divided into bone segments (approximately 2.5 g in weight and 28×7×10 mm in size). The stainless steel materials were 25×5×4 mm in size and approximately 2.5 g in weight. One side of the block was cylindrical, while the other side was spherical. As non-vital bovine bone was used in the study, the ethics committee for animal experiments was consulted. The opinion expressed was that no ethics committee decision was required.

The study was conducted in a laboratory environment with a constant temperature of 28-31°C. The bone segments were stored in a refrigerator at a temperature of 5°C until the study was conducted. The bone segments and stainless steel materials were kept in a saline solution at 28-31°C for 24 hours before the start of the study. In the CryoKB method, 10, 5, 1, and 0.5 minute of cooling were applied.

The temperature changes were recorded using a CEM DT 8869H dual laser infrared (IR) and K-type thermometer (**Figure 1a**) and program called IR Thermometers (**Figure 1b**) version 2.3.1 (Shenzhen Everbest Machinery Industry Co Ltd, Shenzhen, China). The measurement sensitivity of the thermometer was ±0.1% of reading. The temperature measurement was measured with a type K probe by creating a 5-mm-deep and 1.5-mm-wide slot in the bone. In the stainless steel materials, the temperature measurements were recorded from a depth of 5 mm with a K-type probe. Temperature changes were measured every 5 minutes from the baseline (0 minute) to 1 hour.

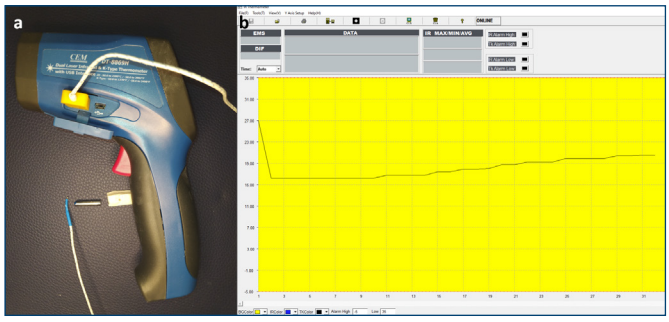

Figure 1a-1b. Temperature changes

The GraphPad Prism version 8 program was used to evaluate the data (GraphPad Software Inc., San Diego, CA). Normality was assessed using the D'Agostina and Pearson omnibus tests. Differences between the groups were assessed using the Kruskal-Wallis test and one-way analysis of variance. When the results were significant, Dunn's multiple comparison test was used to identify which groups were significantly different.

RESULTS

The temperature changes in 52 samples were evaluated. Of these samples, 26 were bovine femur bones and 26 were stainless steel materials. The descriptive statistical information of the temperature changes in the groups is given in **Table 1**. The minimum, maximum, and median temperatures were respectively 2.8°C, 30.9°C, and 29.7°C in the G1 group and –3.4°C, 20.7°C, and 18.9°C in the G2 group.

Table 1. Descriptive statistical information of the temperature changes in the groups

Groups	temperature °C		
	Median	Min; Max	95% CI
G1	29.7	2.8;30.9	25.68 to 29.21
G2	18.9	-3.4;20.7	13.93 to 17.33
K1	30	29.1;30.9	29.86 to 30.16
K2	30	29;30.9	29.84;30.1

While statistically significant differences in temperature change were found between the G1 and G2 groups (X^2=142.9, p<0.0001), no such differences were found between the G1 and K1 groups (X^2=142.9, p=0.0502; **Figure 2**). A statistically significant difference in temperature was found between the G2 and K1 groups (X^2=142.9; p< 0.0001) and, similarly, between the G2 and K2 groups. (X^2=142.9; p< 0.0001; **Table 2**).

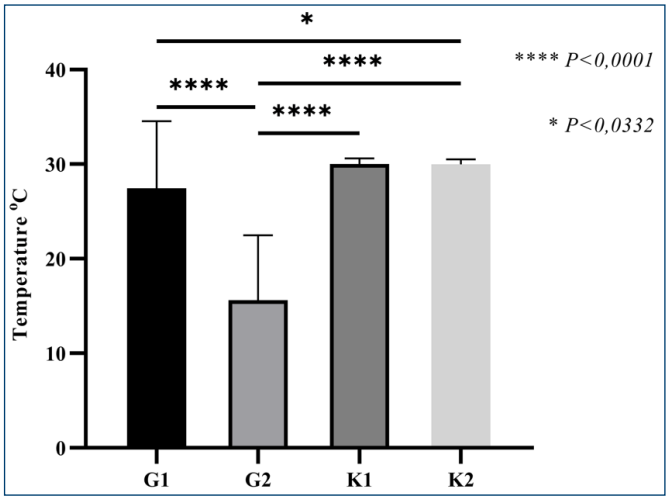

Figure 2. Comparison of temperature change between groups

Table 2. Multiple comparisons between groups

Dunn's multiple comparisons test	Mean rank diff	Mean rank	Kruskal-Wallis statistic	Adjusted P Value
G1 vs. G2	99.27	136.9 vs. 37.62	142.9	<0.0001
G1 vs. K2	-34.76	136.9 vs. 171.6		0.0187
G1 vs. K1	-38.97	136.9 vs. 175.9		0.0502
G2 vs. K2	-133.98	37.62 vs. 171.6		<0.0001
G2 vs. K1	-138.28	37.62 vs. 175.9		<0.0001
K1 vs. K2	-4.208	175.9 vs. 171.6		>0.9999

Diff: differences

From a temperature-time graph, we determined that the temperatures in the K1 and K2 groups were at the level of 29-31°C for a period of 60 minutes. In the G1 group, the temperature was maintained at its lowest level in the first 10 minutes but quickly returned to its initial level. In the G2 group, the temperature decreased to lower than 0°C. The rate of temperature increase was slower in the G2 group than in the G1 group. The temperature was lower than 21°C for the first 45 minutes (**Figure 3**).

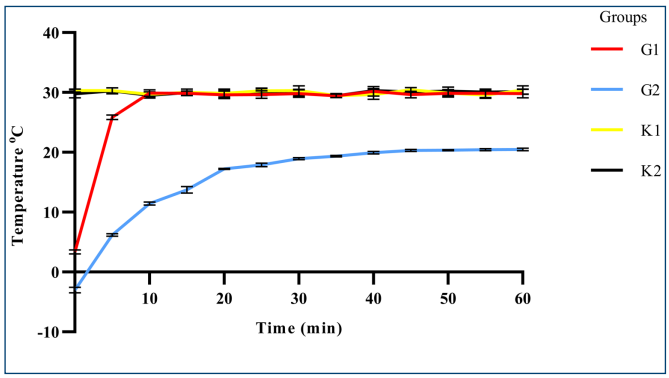

Figure 3. Apperance to temperature-time graph of groups

When the time factor of bone cooling was evaluated, the cooling effect from 10 minutes of cooling was statistically significantly different from that from 5.1 and 0.5 minutes of cooling. In addition, the cooling effect of 5 minutes of cooling was statistically significantly different from that of 1 and 0.5 minutes of cooling. No statistically significant difference in cooling effect was found between 1 and 0.5 minutes of cooling (**Table 3**, **Figure 4**).

Table 3. Evaluation of different cooling times in the cooling of bone.

Dunn's multiple comparisons test	Mean rank diff	Mean rank	Kruskal-Wallis statistic	Adjusted P Value
10 min vs. 5 min	-52.95	69.32 vs.122.3	72.38	0.0004
10 min vs. 1 min	-89.79	69.32 vs. 159.1		<0.0001
10 min vs. 0.5 min	-102.0	69.32 vs. 171.3		<0.0001
5 min vs. 1 min	-36.84	122.3 vs. 159.1		0.0313
5 min vs. 0.5 min	-49.04	122.3 vs. 171.3		0.0012
1 min vs. 0.5 min	-12.20	159.1 vs. 171.3		>0.9999

Diff: differences, min: minutes

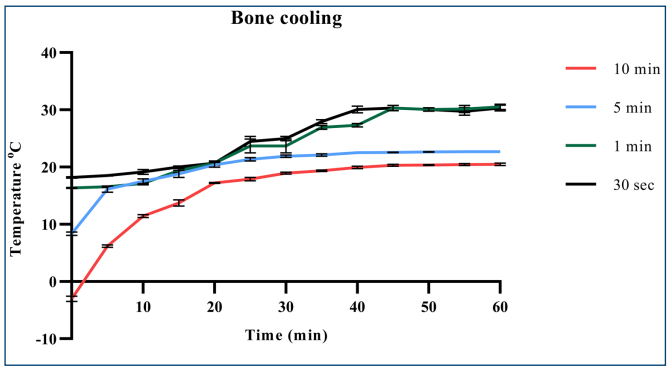

Figure 4. Evaluating time factor of bone cooling

DISCUSSION

Harmful effects may occur when creating the implant socket.[10] Among these harmful effects is thermal necrosis, which is thought to cause early implant loss. Today, irrigation solutions are often used to cool implant drills, but some clinicians do not use them because they impair the visibility of the surgical area.[11] In addition, the desire to use the bone particles that result from the drilling during the operation may also prevent the use of irrigation solutions. In our study, a cooling method without the use of an irrigation solution was designed to ensure both cooling and to overcome the disadvantages of using irrigation solutions. This is the first study to perform cooling using the principle of thermoelectric cooling.

Thermoelectric coolers balance an object's temperature without being affected by the surrounding temperature while lowering the object's temperature below the ambient temperature. Thermoelectric coolers, or Peltier coolers as they are commonly called, are semiconductors that work like a small heat pump.[12,13] They are usually manufactured in the form of semiconductor electrodes placed between two ceramic plates. Owing to the small voltage from a direct current source, heat moves from one end of the module to the other. Thus, while one side of the module heats up, the other begins to cool simultaneously. By adding a liquid tank to the cooling part (**Figure 5a**), cold transfer is ensured using the 4-×6-mm-diameter pipe of the cold and submersible pump (**Figure 5b**). As the thermoelectric cooler introduced herein is smaller than other cooling systems, it can be used in cooling the patient's mouth, except for in vitro studies. Although a deep freezer was used in this study, the intraoral cooling device we designed will be used in future studies.

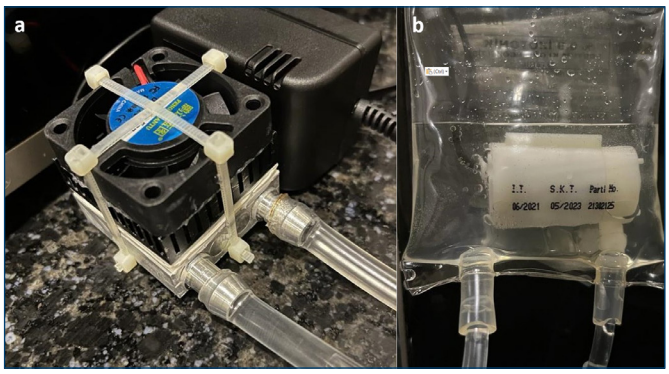

Figure 5a-5b. Cold transfer by adding a liquid tank

Cold therapy has been regularly used to provide analgesia in acute injuries. Its anti-inflammatory effects have also been reported.[14] Another study reported that cold treatment increased antioxidant concentrations. Cold has been shown to reduce inflammatory cytokine levels by increasing adrenaline and noradrenaline levels.[15] In our pilot in vitro study, we found that cooling using the CryoKB method was better than cooling using the traditional irrigation method described in the literature. In the traditional method, cooling the implant drills is preferred, but in our pilot study, cooling the bone provided more effective results than cooling stainless steel materials. This can be explained by the high thermal conductivity coefficient of stainless steel materials (16.2 W/mK) causing the quick transfer of low and high temperatures to the material or air that comes into contact with the blocks.[6,16] However, cortical bone cannot transmit high or low temperatures because of its low thermal conductivity coefficient (0.37-0.47 W/mK).[16]

The heat generated by the friction between the implant drill and the bone is transmitted to the bone in contact with the implant drill because of the high thermal conductivity of the drill. A temperature increase occurs in the bone in proportion to the amount of heat transmitted. Here, the formula used to calculate the temperature increase was – Q=m c ΔT, where Q is the amount of heat transferred and ΔT is the change from the initial temperature (Ti) to the final temperature (Tf). When the amount of heat transferred and the mass of matter are considered constant, the low Ti of the bone causes its Tf to be low.[17] The logic of the CryoKB method is to reduce the temperature of the bone before the operation and to ensure that the temperature increase as a result of the heat transfer is limited.

While 47-55°C for 1 minute is known to be the threshold value of the thermal change in the bone before necrosis develops, a cold temperature of 3.5°C has histological effects.[18] In another study, the effects of hot and cold temperatures on bone were evaluated. Applying 51°C for 10 seconds and 5°C for 30 seconds created significant matrix degeneration. In osteocytes, deaths have been reported from 49°C up to 56°C. Osteocyte deaths at cold temperatures started at 5°C but showed a statistically significant difference in temperature of 1°C.[19]

The cooling time is important for applications in clinical studies. The longer the cooling time, the more and longer the cooling effect is expected to last.[20] In this study, long-term cooling lowered the bone temperature to less than 0°C. However, even after 0.5 minutes of cooling, the temperature remained lower than 20°C for the first 10 minutes. It is thought that 0.5 seconds of cooling will be sufficient for clinical studies.

CONCLUSION

Although our study was conducted at room temperature, the cooling of the bone and application of the CryoKB method did not increase the room temperature during the study period (60 minutes) and maintained the cold temperature. However, when irrigation methods and cooling techniques with stainless steel materials were used, the temperature of the material used returned to room temperature in less than 10 minutes. The advantage of the newly developed CryoKB method is that it is not affected by room temperature, unlike the traditional methods. The small number of samples and the in vitro design of the study can be considered as its limitations. The method of bone cooling without an irrigation solution caused more cooling of the bone than the traditional irrigation method. On the basis of the results of this study, temperature changes in the bone should be detected by applying in vitro drilling procedures.

ETHICAL DECLARATIONS

Ethics Committee Approval: This study has been evaluated by the Animal Experiments Local Ethics Committee Presidency of Kırıkkale University Rectorate within the scope of diagnostic and therapeutic clinical applications, and it has been concluded that there is no need for an Ethics Committee decision (Date: 08.06.2022, Decision No: E-100143).

Informed Consent: Because of designed of the study, no written informed consent form was obtained.

Referee Evaluation Process: Externally peer-reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Financial Disclosure: Kırıkkale University Scientific Research Projects Coordination Unit supported the study (Project No: 2022/068).

Author Contributions: All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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