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Heat generation during osteotomy performed with ultrasonic insert versus rotary instrument in bovine femur: *ex vivo* comparison

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ABSTRACT

Osteotomy procedures in dentistry are usually performed with drills, but piezosurgical instruments have also been used to improve surgical conditions for both the patient and the operator. This ex vivo study uses infrared thermography to analyze heat generation in osteotomies. ***Aim:*** *The aim of this study was to conduct an infrared thermographic comparison of the heat generated by an ultrasonic insert, either with or without an aerosol dispersion control device, in contrast to a conventional bur, during osteotomy procedures performed on bovine femur specimens.* ***Materials and Method:*** *Osteotomies were performed on nine bovine femur blocks, with each osteotomy consisting of a linear cut 12 mm long and 3 mm deep. Each block underwent a single cut from each instrument examined. The osteotomies were divided into three groups according to the instrument used: Group CARB, carbide bur #701; Group INS, #SFR4 ultrasonic insert coated with diamond-like carbon (DLC); and Group INS-S, #SFR4 ultrasonic insert coated with DLC in combination with an aerosol dispersion control device ("spray control"). All incisions were standardized using an automated device. Thermal variations (ΔT) were assessed using an infrared thermographic camera. The maximum (Tm) and minimum (T0) temperatures recorded were utilized to calculate ΔT, following the equation: ΔT = Tm – T0. Statistical analyses were conducted using Kruskal-Wallis test and Dunn's test for multiple comparisons (p < 0.05).* ***Results:*** *The T0 and Tm recorded for INS (21.5°C ± 0.7°C and 23.2°C ± 0.7°C) and INS-S (20.8°C ± 0.4°C and 21.8°C ± 0.4°C) were significantly higher (p < 0.05) than for CARB (14.9°C ± 0.8°C and 17.6°C ± 1.1°C, respectively). The observed ΔT for INS (1.7°C ± 0.4°C) and INS-S (1.0°C ± 0.4) were significantly lower (p < 0.05) than for CARB (2.7°C ± 1.1°C). No significant difference in ΔT was observed for the other comparisons.* ***Conclusion:*** *INS and INS-S produced significantly higher temperatures than CARB. Use of the "spray control" device resulted in a reduction of the temperature variation observed for the piezoelectric insert.*

Keywords: *dental implants - osteotomy - piezosurgery - femur - thermography.*

Geração de calor durante a osteotomia realizada com inserção ultrassônica versus instrumento rotatório em fémur bovino: comparação *ex vivo*

RESUMO

Procedimentos de osteotomias em odontologia são comumentes realizados com brocas, porém intrumentos piezocirúrgicos também vem sendo utilizados com o intuito de se melhorar as condições cirúrgicas tanto para o paciente quanto para o operador. Este estudo ex vivo analisou a geração de calor em osteotomias usando termografia infravermelha. ***Objetivo:*** *Este estudo conduziu uma comparação termográfica infravermelha do calor gerado por insertos ultrassônicos, com ou sem dispositivo de controle de dispersão de aerossol, em relação à broca convencional em osteotomias em fêmures bovinos.* ***Materiais e Método:*** *As osteotomias foram realizadas em 9 blocos de fêmur bovino com cortes lineares medindo 12 mm de comprimento e 3 mm de profundidade. Os instrumentos foram divididos em grupos: Grupo CARB, broca carbide #701; Grupo INS, inserto ultrassônico #SFR4 revestido com carbono tipo diamante (DLC); e Grupo INS-S, inserto ultrassônico #SFR4 revestido com DLC com dispositivo de controle de dispersão de aerossol ("controle de spray"). Todas as incisões foram padronizadas usando um dispositivo automatizado. As variações térmicas (ΔT) foram avaliadas usando uma câmera termográfica infravermelha. As temperaturas máximas (Tm) e mínima (T0) registradas foram utilizadas para calcular ΔT: ΔT = Tm – T0. As análises estatísticas foram conduzidas usando o teste Kruskal-Wallis e teste de Dunn para comparações múltiplas (p < 0,05).* ***Resultados:*** *O T0 e o Tm registrados para INS (21,5 °C ± 0,7 °C e 23,2 °C ± 0,7 °C) e INS-S (20,8 °C ± 0,4 °C e 21,8 °C ± 0,4 °C) foram significativamente maiores (p < 0,05) do que para CARB (14,9 °C ± 0,8 °C e 17,6 °C ± 1,1 °C, respectivamente). O ΔT observado para INS (1,7ºC ± 0,4ºC) e INS-S (1,0ºC ± 0,4) foi significativamente menor (p < 0,05) do que o de CARB (2,7ºC ± 1,1ºC). Não foram observadas diferenças significativas no ΔT para as outras comparações.* ***Conclusão:*** *Os grupos INS e INS-S produziram temperaturas significativamente maiores em comparação ao grupo CARB. O uso do dispositivo "spray control" resultou em uma redução da variação de temperatura observada para o inserto piezoelétrico.*

Palavras-chave: *implantes dentários - osteotomia - piezocirurgia – fêmur - termografia.*

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INTRODUCTION

Osteotomy is a surgical procedure often used in dentistry for applications such as tooth extractions, implant placement, bone grafting and orthognathic surgery. It has traditionally been performed with handpieces and rotary surgical burs, but in recent years, ultrasonic instruments have emerged as an alternative. They provide better visualization of the surgical site, selective cutting of hard tissues, and less surgical trauma[1].

When osteotomies are performed with conventional rotary instruments, there are often postoperative complications such as pain, swelling, trismus and paresthesia. Conventional instruments can also reach exceedingly high temperatures during the procedure, thereby predisposing to local osteonecrosis and hindering bone regeneration and repair[2]. Piezoelectric devices are a promising alternative to traditional instruments. Piezoelectricity is a physical phenomenon that generates mechanical vibrations in ceramics or quartz crystals, facilitating the separation of solid interfaces, including bone tissue[3,4].

Owing to its selective cutting capability, piezosurgery has been employed to mitigate trauma to hard tissues and prevent soft tissue injuries. However, the surgical time required is longer than for conventional approaches[5]. In response to this concern, manufacturers have developed coatings such as diamond-like carbon (DLC) to increase the efficiency of piezoelectric instruments. DLC increases bur hardness, heat resistance, and decreases the coefficient of friction between the bur and tissue, thereby reducing heat generation during the procedure and mitigating instrument wear, darkening and corrosion[6].

Another relevant factor is the control of aerosol generation during dental procedures conducted with rotary, ultrasonic or piezoelectric instruments. The importance of aerosol generation has been highlighted, particularly as from the COVID-19 pandemic, when the American Dental Association reported that SARS-CoV-2 particles can be dispersed via the aerosols generated by dental equipment, thereby amplifying the risk of cross-contamination. To satisfy increasingly strict biosafety standards, manufacturers are producing dental equipment designed to mitigate aerosol dissemination[7].

The temperature increase and the heat conveyed to the tissues as a result of an osteotomy depends on various factors, including bone pattern, cutting speed and pressure, bur design and longevity, and irrigant temperature and volume, among other factors. All these variables should be managed to ensure better postoperative outcomes[8,9]. However, there are few studies comparing the heat generated by piezoelectric devices versus conventional rotary instruments, and few devices that control aerosol generation adequately. There is therefore a need for research to determine which instruments are best to ensure that osteotomies are precise and safe, thereby fostering more predictable and uneventful postoperative periods. The aim of this study was to conduct an infrared thermographic evaluation of the heat produced by an ultrasonic insert, with or without an aerosol dispersion control device, in comparison to a conventional bur, throughout the execution of osteotomies in bone blocks sourced from bovine femurs.

MATERIALS AND METHOD

Experimental design

This study was exempt from evaluation by the Institutional Research Ethics Committee (registration no. 2021-1158) because it did not involve human subjects or experimental animals. The study used nine bovine femur bone blocks approximately 6 cm long and 1 cm wide, obtained from a slaughterhouse. Each bone block underwent three osteotomies, resulting in a total 27 osteotomies performed for the study.

The sample size of 9 bovine femur blocks provided test power above 95%, with a significance level of 5%, for the effect sizes found in the trial. These calculations were performed using R[10] and G*Power[11] software.

Osteotomy procedure

Three linear incisions 12 mm long and 3 mm deep were made – one with each instrument – on the cortical surface of each bone block (Fig. 1). The experimental groups were:

- **Group CARB**: incisions made with carbide bur #701 (Komet, Santo André, SP, Brazil),
- **Group INS**: incisions made with #SFR4 ultrasonic insert coated with DLC (CVDentus, São José dos Campos, SP, Brazil), and
- **Group INS-S**: incisions made with #SFR4 ultrasonic insert coated with DLC, in conjunction with an aerosol dispersion control device ("spray control"; CVDentus).

Fig. 1: Bovine femur bone blocks after performing the osteotomies.

Fig. 2: Carbide bur #701 used in the study.

In Group CARB, the #701 carbide bur was driven by a high-speed turbine (Extra Torque 505C; Kavo Kerr, Biberach, Germany) under water cooling (Fig. 2). In Groups INS and INS-S, the incisions were made by a previously trained operator, and temperature was assessed by two independent evaluators. The #SFR4 inserts, either with or without "spray control" (Fig. 3), were driven by a piezoelectric motor (DentSurg PRO; CVDentus), set to operate in cortical bone surgery mode and level 5 irrigation, following the manufacturer's recommendations. Cooling during the procedure was performed using 0.9% saline solution at room temperature (21°C).

In Group CARB, the turbine was attached to a device designed to automate the controlled horizontal motion of the bone block. The incisions were executed over a duration of 30 s, with a constant pressure of 57.85 g applied to the bur tip. The pressure was standardized by placing metal nuts along the stem of the automated device. Two nuts were employed to ensure the stability of the turbine during motion, and the overall weight of the turbine assembly was gauged using a precision scale. The turbine was operated by a foot pedal, the specimens in this group were irrigated with filtered water at room temperature.

In Group INS, the handpiece of the motor was connected to the same cutting automation device. Bone blocks were positioned in the device, and preliminary perforation markings were initiated with the insert, without pre-set pressure, to delineate the

Fig. 3: #SFR4 ultrasonic inserts, with and without "spray control," used in the study.

Fig. 4: Position of the insert with "spray control" in the automated cutting device.

intended incision paths on the bone. The incisions were executed over a period of 30 s, with a constant pressure of 57.85 g. Pressure was standardized as in Group CARB.

In Group INS-S, the same protocol was implemented (Fig. 4). A new #SFR4 ultrasonic insert was allocated to each of the INS and INS-S groups. In all experimental groups, Evaluator #1 numbered the bone blocks and placed them on the device in a randomized sequence generated through www.random.org, while Evaluator #2 took videos and photographs.

Laboratory ambient temperature was maintained constantly at 21°C using an air conditioning system.

Thermographic analysis

Thermal variations (ΔT) were assessed with an infrared thermographic camera (FLIR C5; Teledyne Flir, Wilsonville, OR, USA), and computed by determining the difference between the maximum (Tm) and minimum (T0) temperatures recorded (ΔT = Tm – T0).

The camera was fixed to a tripod, perpendicular to the bone block, at a distance of 30 cm (Fig. 5). Throughout the osteotomy procedure, the thermographic camera gathered ΔT data in °C, while a conventional video camera recorded the readings displayed on the thermographic camera. This procedure was adopted because the rapid fluctuation of values on the camera display made it difficult to record them manually.

The camera also acquired thermal images of the procedure at 10 and 30 s, with temperature recordings taken at both timepoints. The infrared thermographic measurements were conducted with

Fig. 5: Position of the infrared thermographic camera during the experiment.

specified parameters, including emissivity (ε) 0.90, reflected temperature 20°C, relative humidity 50%, and ambient temperature 21°C. The crosshairs of the camera were precisely aligned over the point of intersection between the images of the bone block and either the bur or insert (Figs. 6 and 7).

Statistical analysis

Data distribution was assessed with the Shapiro-Wilk test, indicating a non-normal distribution. Consequently, the Kruskal-Wallis non-parametric test was used to compare data across the experimental groups. Multiple comparisons were conducted utilizing Dunn's test. Statistical analyses were performed using SPSS v. 23 (SPSS, Chicago, IL, USA) and BioEstat v. 5.0 software (Mamirauá Foundation, Belém, PA, Brazil). The significance level was set at 5%.

RESULTS

The T0 and Tm values recorded for INS (21.5°C ± 0.7ºC and 23.2ºC ± 0.7ºC, respectively) and for INS-S(20.8ºC ± 0.4ºC and 21.8ºC ± 0.4ºC, respectively) were significantly higher than for CARB (14.9ºC ± 0.8ºC and 17.6ºC ± 1.1ºC, respectively). ΔT for INS-S was significantly lower than that for CARB ($p < 0.05$). ΔT was 1.7ºC ± 0.4ºC for INS, 1.0ºC ±

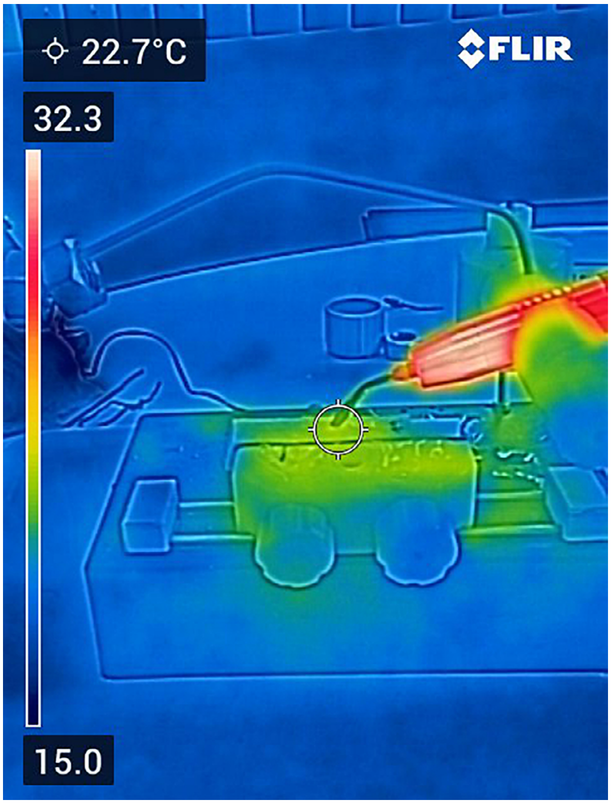

Fig. 6: Thermal image obtained during the osteotomy performed with the ultrasonic insert. Piezoelectric insert positioned over the bone block, which was attached to the automated cutting device. The photo was taken by the thermographic camera at the time the osteotomy was performed and shows the temperature of the delimited target.

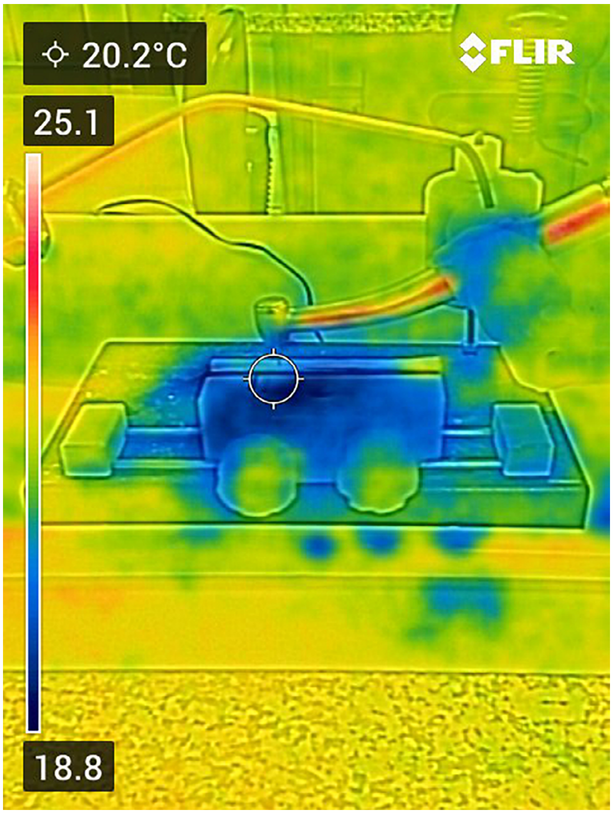

Fig. 7: Thermal image obtained during the osteotomy performed with the carbide bur. Carbide bur positioned on the bone block, which was attached to the automated cutting device. The photo was taken by the thermographic camera at the time the osteotomy was performed and shows the temperature of the delimited target.

0.4 for INS-S and 2.7ºC ± 1.1ºC for CARB. INS attained an intermediate ΔT level, and did not differ significantly from the ΔT values for the other groups ($p > 0.05$); (Table 1).

DISCUSSION

Twenty-seven osteotomies were conducted on bovine femurs, and the heat generated by the instruments was quantified through infrared thermographic analysis. The aim of this study was to find data that would help improve understanding of the range of available osteotomy instruments and the intraoperative temperature elevation they induce.

Bovine femur was used because of its structural resemblance to human bone, and its high density and uniformity in the cortical region, which provide a high level of friction between the instrument and the bone surface[1,9,12-14]. Bone density is a significant factor influencing the thermographic variations observed during osteotomy procedures[15].

In the literature, there is a lack of consensus regarding the optimal *in vitro* model for investigating heat generation in osteotomies. Various authors[4,16-18]

Table 1. Mean, standard deviation and median values of minimum temperature (T0), maximum temperature (Tm) and temperature variation (ΔT; in °C) observed for the experimental groups.

Experimental groups		T0	TM	ΔT
CARB	Mean (SD)	14.9^{A} (0.8)	17.6^{A} (1.1)	2.7^{B} (1.1)
	Median	14.7	18.1	2.9
INS	Mean (SD)	21.5^{B} (0.7)	23.2^{B} (0.7)	1.7^{AB} (0.4)
	Median	21.8	23.3	1.6
INS-S	Mean (SD)	20.8^{B} (0.4)	21.8^{B} (0.4)	1.0^{A} (0.4)
	Median	20.9	21.9	0.9
p-value		$p < 0.001$	$p < 0.001$	$p = 0.001$

CARB: carbide bur #701; INS: #SFR4 ultrasonic insert coated with diamond-like carbon (DLC); INS-S: #SFR4 ultrasonic insert coated with DLC and utilized in conjunction with a “spray control” device. Means followed by different capital letters within the column denote a statistically significant difference between groups (Kruskal-Wallis and Dunn tests; $p < 0.05$).

have used different experimental models, including rabbit tibia, porcine rib, bovine rib, porcine mandible, and synthetic bone blocks with varying densities. In most of these studies, the osteotomies were perforations made with implant burs, rather than linear cuts, which justifies a greater concern of these authors in simulating in several models of different bone densities found, such as bone types I, II, III, and IV. Considering the clinical applications of osteotomies with linear incisions in more cortical areas, further studies are needed to standardize the ideal model.

Infrared thermography can be used for non-invasive monitoring of temperature alterations on the outer surface of the bone and the visible portion of the bur. It is often used in research to evaluate thermographic variations in animal tissues and organs[6,19,20]. Other authors have used digital thermometers and thermocouples for temperature-related research[18,21,22].

Thermocouples can measure temperatures at a single point, but require attachment perforations in the bone, rendering them relatively more invasive. Conversely, infrared thermography provides a thermal profile of the material, including leakage heat, but can only detect surface temperature[23]. Accordingly, Harder et al.[24] compared infrared thermography to thermocouples for measuring heat generation and concluded that thermography is more accurate for measuring changes in intraosseous temperature.

In the current study, osteotomy cut standardization was based on Delgado-Ruiz et al.[25], and thermographic analysis methodology was based on Gabrić et al.[26] and Scarano et al.[27]. In Group CARB, the cutting process was characterized by greater instrument vibration, particularly at the beginning, when the cutting path was being delineated, whereas the cuts executed with the ultrasonic inserts were more accurate and linear.

The mean T0 and Tm values recorded for INS (21.5°C ± 0.7°C and 23.2°C ± 0.7°C, respectively) and INS-S (20.8°C ± 0.4°C and 21.8°C ± 0.4°C, respectively) were significantly higher than those observed for CARB (14.9°C ± 0.8°C and 17.6°C ± 1.1°C, respectively). However, they remained considerably lower than the temperature threshold associated with osteonecrosis, which manifests when the bone is subjected to a temperature of 47°C for one minute[28]. Sagheb et al.[29] report temperatures of 37°C ± 1°C for conventional burs and 36°C ± 1°C for piezosurgical inserts in cortical bone, based on photos taken by a thermographic camera. Although these values are higher than those recorded in the present study, heat generation did not differ significantly among the experimental groups.

Aquilanti et al.[16] used a thermographic camera to assess heat generation during initial osteotomies for implants in synthetic bone blocks, reporting averages of 19.58°C ± 1.11°C for rotary burs and 84.10°C ± 40.98°C for piezosurgical inserts. These values are substantially higher than those observed in the present study, and surpass the clinically safe threshold. The authors concluded that piezosurgical inserts induced a significantly greater temperature increase compared to burs, which is consistent with the results of the present study. Conversely, Rashad et al.[30] used thermocouples to compare sonic and ultrasonic inserts to conventional burs in bovine ribs, finding that both ultrasonic and sonic osteotomies generated significantly lower heat than conventional osteotomy did. None of the instruments tested in their study exceeded the critical heat threshold.

Gabric et al.[26] compared Er:YAG laser, piezosurgical inserts, and conventional burs, reporting average Tm values of 79.1°C ± 4.6°C for laser, 29.1°C ± 0.2°C for inserts, and 27.3°C ± 0.4°C for burs. While the average Tm values for inserts and burs were higher than those observed in the present study, the ΔT observed for the inserts was consistent.

One limitation of the current study was that although bovine femur was used due to its high density, the study did not quantify specimen bone quality, which may influence the temperatures generated. In this regard, Sagheb et al.[29] used ultrasound transmission velocity, which is considered reliable and safe for bone quality testing, especially in *ex vivo* samples.

Another limitation of the current study is that the osteotomies were performed on bone blocks at room temperature, after storage under refrigeration and removal one day before the procedure. In other studies[31], the bone blocks were stored in a water bath prior to the procedure, and heated to 36°C to simulate body temperature.

In the present study, the temperatures recorded in all three groups remained below the limit considered safe for performing osteotomies. Although variations in heat generation were observed between the instruments tested, it can be argued that the clinical significance of this finding is limited, since this is an *ex vivo* study, with limitations inherent to this type of model, which does not include the variables present in an *in vivo* study.

In Group INS-S, ΔT was significantly lower than in Group CARB, while in Group INS, ΔT remained at an intermediate level, statistically similar to that observed in the other groups. This suggests that the device developed with the primary aim of safeguarding the operative field against generated aerosols not only increased intraoperative biosafety, but also guided the irrigation drip of the inserts, thereby effectively managing temperature levels. Consequently, the aerosol protection device utilized in INS-S can be deemed effective in contributing to temperature regulation in clinical scenarios in which piezoelectric ultrasound is used. This device has a silicone cover attached to the rod of the ultrasonic insert, extending to its working tip[7], and can be autoclaved.

While the conventional bur employed in CARB yielded the lowest temperatures, its ΔT was significantly higher. This can be attributed to three factors: (1) the substantially greater irrigation it provides compared to piezoelectric inserts; (2) occasional deviations in the direction of the water jet emitted from the handpiece due to inadequate calibration; and (3) the dispersion of the aerosol during use.

Bernabeu-Mira et al.[6] posit that instruments without DLC coating may undergo considerable wear over time, thereby inducing greater friction and heat generation. In the present study, although the inserts utilized in Groups INS and INS-S had DLC coating, their temperatures were higher. Nevertheless, these temperatures remained constant, and the corresponding ΔT levels were lower than those observed in Group CARB, which lacked a DLC coating.

The initial contact between the bur and the bone tissue typically occurs in the cortical region, which generates more heat due to the pressure required to produce the initial rupture of the bone plate[4]. This trend was observed during the current study, as evidenced by the highest temperatures being recorded at the beginning of the procedures.

There is still a need to develop a device integrating all the properties required to ensure a swift, safe surgical procedure. Although piezosurgery ensures safety, it requires longer surgical intervention time. Hence, the system should be selected based on the operator's expertise. Combining both systems may prove advantageous, depending on the nature of the procedure to be conducted[2,5].

The DLC-coated piezoelectric inserts, with or without "spray control," employed in the present study produced significantly higher temperatures compared to the carbide bur. Nevertheless, incorporation of the aerosol dispersion control device in conjunction with the insert yielded a significantly lower ΔT compared to the conventional bur. Further research may provide a more comprehensive evaluation of this device and its functionalities.

CONCLUSION

The DLC-coated piezoelectric inserts generated significantly higher temperatures compared to the high-speed carbide bur. However, use of the aerosol control device mitigated the temperature variation associated with the inserts.

CONFLICT INTERESTS

The authors declare no potential conflicts of interest regarding the research, authorship, and/or publication of this article.

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