Intraosseous Heat Production and Preparation Efficiency of Surgical Tungsten Carbide Round Drills: The Effect of Coronectomy on Drill Wear

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Purpose: The aim of this in vitro study was to examine the effects of surgical drill wear after coronectomy on bone temperature changes and preparation times for bone cavity drilling.

Materials and Methods: Tungsten carbide round drills were used to perform 10 (D_10), 20 (D_20), or 30 (D_30) coronectomies on extracted lower third molars to elicit drill wear, and then 5-mm-deep cavities were drilled in pig ribs with a testing apparatus-controlled surgical unit. Temperature changes and preparation times were measured. Differences in mean values were examined with analyses of variance and the Tukey honest significant difference post hoc test.

Results: The unused drills prepared the holes significantly faster (2.52 ± 1.6 seconds) than the D_20 (13.29 ± 5.76 seconds) and D_30 (31.48 ± 12.93 seconds) drills (P = .01 and P < .001, respectively). The D_10 (change, 2.33 ± 0.77°C), D_20 (change, 2.57 ± 0.57°C), and D_30 (change, 3.94 ± 0.62°C) drills produced significantly more heat than the D_0 drills (change, 1.18 ± 0.28°C; P < .001). At higher axial pressures of 25 N (to provoke ≤3-second preparation times in line with new drills), the D_30 drills produced a temperature change of 6.31 ± 1.23°C with 60 mL/minute and significantly more heat (change, 20.48 ± 8.84°C; P < .001) with 20 mL/minute of irrigation.

Conclusions: Intraosseous heat produced by surgical tungsten carbide round drills remains under the threshold temperature of bone necrosis for up to 30 coronectomies; however, the use of increased axial pressure (~25 N), especially with the combination of decreased irrigation (~33%), can cause unacceptable temperatures during bone removal. Professionals should select drills and drilling parameters that
Q3 generate an acceptable amount of heat during surgical tooth removal.

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Bone removal and drilling are typical processes in medicine, including dentistry, oral and maxillofacial surgery, ear, nose, and throat surgery, orthopedics, and traumatology. Although the use of piezoelectric or laser devices for bone preparation is gaining popularity in oral and maxillofacial surgery, drills are frequently used for surgical tooth removal.[1-3] The removal of impacted teeth, such as lower third

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molars, is usually impossible without some degree of bone removal. Wear on surgical drills during these procedures is pronounced because of frequent unintentional tooth contact and the need for sectioned tooth removal. However, multiple crown and tooth sections (usually necessary at horizontal, distoangular, and mesioangular impactions) seem to present the greatest challenge for drills; drill wear also is increased during coronectomy, which is a reliable method for avoiding inferior alveolar nerve injuries.[4,5] Heat production during bone drilling is a well-investigated subject. Parameters related to bone drilling, such as drilling speed, axial pressure on the drill (feed rate), cooling (external, internal, or combined), drilling depth, predrilling, and bone cortical thickness, greatly influence the amount of heat generated.[6,7] Furthermore, intraosseous heat production is influenced by drill design, diameter, material, and wear.[6,7] The use of extremely worn drills can result in longer preparation times and increased heat production, which can result in thermal osteonecrosis (ON). Bone necrosis is the result of intracellular enzymatic and membrane protein denaturation, cell desiccation and dehydration, membrane rupture, and carbonization.[6,8,9] Thermal ON can lead to compromised wound healing after tooth removal and, in implant surgery, can impair osseointegration.[8,10]

The typically accepted threshold temperature and "danger zone" for bone survival is 47°C for longer than 1 minute; however, higher temperatures might require less time to potentially result in the development of necrosis or complicate bone healing.[11,12] Independent of heat production, drilling can cause micro-damage to the bone. These small cracks of the mineralized matrix can lead to apoptosis, depletion of osteocytes, and a decrease in blood flow that increases the risk of ON.[7,13] The greater thermal and mechanical trauma caused by worn drills can frequently induce bone necrosis and compromised blood flow, which can increase the risk of alveolitis. In addition, tooth sectioning has been reported as an etiologic factor in the development of delayed-onset infections after third molar extraction.[14] According to Noroozi and Philbert,[15] much of the literature supports a correlation between surgical trauma and dry socket, the incidence of which was reported to be 25 to 30% after the removal of impacted mandibular third molars.[16]

Unfortunately, in contrast to frequently examined twist drills, there are no guidelines or descriptions on how many times the tungsten carbide round drills used in oral and maxillofacial surgery can be used without causing thermal ON during bone removal. Moreover, the characteristic signs of a potentially unacceptable degree of wear, with the typical macroscopic appearance of the drill, and their effects on actual heat productions are unknown by clinicians. In addition, oral and maxillofacial surgeons can expect similar performances from worn and unworn drills; thus, the effects of forced usage on bone temperatures also are unknown.

The aim of this in vitro study was to examine the effects of a defined number of tooth sectionings (coronectomies) on drill wear and the effects of drill wear on bone preparation efficiency and concurrent intraosseous heat generation. Another aim was to examine the macroscopic appearance of the worn drill that should not be reused.

Materials and Methods

EXPERIMENTAL DESIGN

In this in vitro study, surgical tungsten carbide round drills (HM141 A; Hager & Meisinger GmbH, Neuss, Germany) with diameters of 3.1 mm were tested. These drills exhibited effective performances in the authors' previous studies of third molar removals.[17,18] The drills were divided into the following 4 groups according to the number of coronectomies performed with each drill: new, unused drills (D_0); drills after 10 procedures (D_10); drills after 20 procedures (D_20); and drills after 30 coronectomies (D_30; Fig 1).

Eighteen pig rib specimens with an average cortical thickness of 2.1 to 2.3 mm were used to simulate the retromolar area of the human jawbone. Each bone was taken from 1 of 3 8-month-old male animals (~120 kg). The animals were not sacrificed for the experiment. The 50-mm long bone specimens were stored at −10°C in frozen saline. Before the experiments, sufficient time was provided for the specimens in the saline tanks to reach room temperature, and they were continuously kept wet until their use.

The experimental apparatus functioned with a commercially available physio-dispenser surgical unit (Implantmed SI-915; W&H, Bürmoos, Austria) and with a surgical handpiece with external cooling (SL-11; W&H; Fig 2A). The apparatus enabled the setting of a constant drilling depth and axial pressure (with the help of weights; Fig 2B). The apparatus was secured to the drill perpendicularly into the bone surface, and the surgical unit ensured that the parameters, including drilling speed and irrigation, were constant and similar to those encountered in clinical environments. The apparatus measured the preparation time (milliseconds) from the initiation of preparation until the exact predetermined depth was reached.

Temperature measurements were recorded with type K thermocouple devices (Ø = 0.5 mm; Cu/CuNi; TC Direct, Budapest, Hungary) that were coupled with a digital thermometer (EL-EnviroPad-TC, Lascar Electronics Ltd, Salisbury, UK), with a

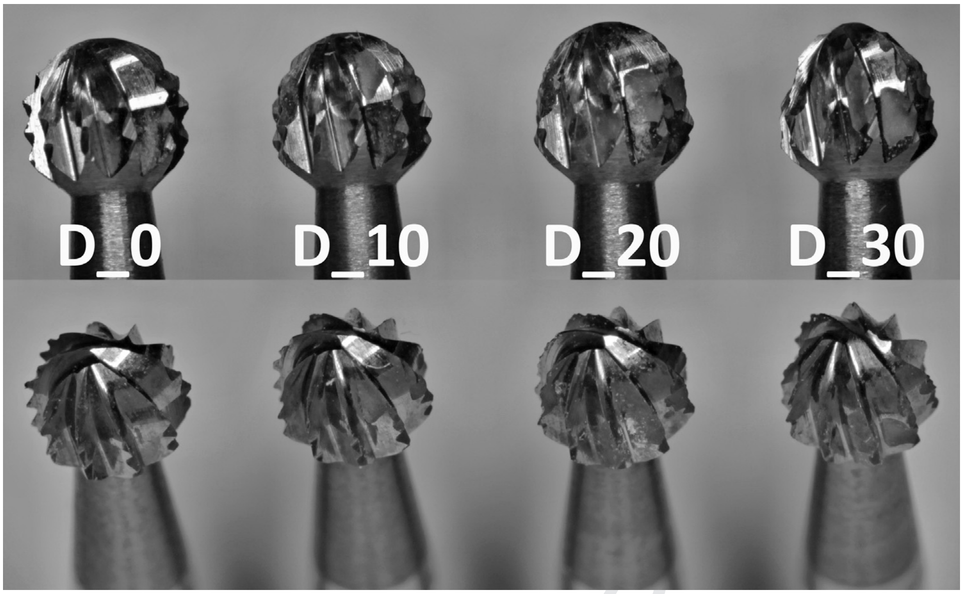

FIGURE 1. Macrographic photographs of investigated drills. The cutting edges at the tops of the drills became blunter with increased wear, and larger portions of the cutting lips were missing. In the D_20 and D_30 drills, the cross-cut cutting edges were severely damaged. D_0, new drill; D_10, drill after 10 coronectomies; D_20, drill after 20 coronectomies; D_30, drill after 30 coronectomies. Q4

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resolution of 0.1 per 1°C and a data sampling frequency of 1 measurement per second (Fig 2C).

The thermocouple sensors were vertically positioned at a distance of 1 mm from the osteotomy holes and secured with the aid of a drill guide template. The metal rectangular template was positioned and fixed with slots on the bone fixating “box” (Fig 3). The bone fixating box had 4 predetermined locations for the testing apparatus, and each of these locations was secured in the exact position of the tested bone perforations and the cavities of the sensors according to the markings on the guide (Figs 2C, 3). The 5-mm-deep cavities for the sensor placement were prepared with a 0.5-mm-diameter stainless steel twist drill (203 RF; Hager & Meisinger GmbH). Possible discrepancies between the bone cavity and the sensors were filled with thermal paste (Arctic Silver 5, Scan Computers International Ltd, Bolton, UK). To prevent any interference, the sensors were isolated from the irrigation solution by embedding them into 2-cm-long pieces of rubber tube (prepared from the rubber tubes of 22-gauge wing “scalp” infusion sets; B. Braun Melsungen AG, Melsungen, Germany) that were fixed to the bone surfaces with dental bond (OptiBond Solo Plus, Kerr Corp, Orange, CA; Fig 2C).

Each experiment was conducted and the full apparatus was stored in the same air-conditioned room at a room temperature of 24°C.

Each drill (D_0, D_10, D_20, and D_30) was used to prepare 12 cavities in the specimens with 60 mL/minute of irrigation and at 6 N (600 g) of loading force (n = 48 holes). Four drillings could be made in each of the 5-cm-long specimens; thus, each drill (from D_0 to D_30) was used in all specimens. Two additional D_30 drills were used to perform another 24 drillings at higher axial pressure (25 N of force was necessary, which equated to 2,500 g of weight on the specific plate of the apparatus; Fig 2B) to simulate drilling within 3 seconds in line with new drills. With these 2 drills, 12 holes were created with 60 mL/minute of irrigation and 12 holes were created with the irrigation decreased to 20 mL/minute.

STATISTICAL ANALYSIS

Data collection and statistical analyses were performed with SPSS 20.0 (SPSS, Inc, Chicago, IL). The Kolmogorov-Smirnov test was applied to test the normality of data distribution for each group. Changes in heat and preparation time were compared among groups with 1-way analysis of variance followed by the Tukey honest significant difference (HSD) post hoc test. *P* values less than .05 were considered significant.

Results

The characteristic appearance of worn drills is displayed in Figure 1. With increased usage, larger portions of the cross-cut lateral cutting edge became damaged. After 20 coronectomies (D_20), the cutting lips of the top areas of the drills became visibly blunter. After 30 coronectomies, the cross-sections of the cutting lips were nearly completely absent, and the round macroscopic appearance was lost.

FIGURE 2. *A*, A special experimental apparatus controlled the physio-dispenser unit during testing. **(Fig 2 continued on next page.)**

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The heat production and preparation times of the different drills are presented in Table 1. The D_30 drills with increased axial pressure and decreased irrigation caused an average temperature increase of 20.48°C and a maximum increase of 37.8°C. Calculations of temperature changes from the 37°C human baseline temperature indicated a mean of 57.48°C and a maximum of 74.8°C. Temperatures higher than 47°C were in the danger zone and never lasted longer than 20 seconds. Differences in mean temperatures elicited by the different drills were statistically significant ($P < .001$ by analysis of variance). Post hoc tests showed that differences only between the D_30 drills with 6 N and the D_30 drills with 25 N of loading (at equal irrigations of 60 mL/minute) and between the D_10 and D_20 drills did not reach significance ($P = .516$ and $P = .744$, respectively, by Tukey HSD post hoc test; Table 2, Fig 4). Figure 5 illustrates the dynamics of the temperature data of a randomly selected experiment. As shown in Figure 5, the drills with more wear caused higher temperatures and slower increases and decreases. Furthermore, temperatures observed with the D_10, D_20, and D_30 drills did not decrease to baseline values within 120 seconds.

Preparation time data indicated that drilling with the D_10 drills was not slower than drilling with the D_0 drills ($P = .294$ by Tukey HSD post hoc test) and that the drilling times of the D_20 and D_10 drills were similar ($P = .425$ by Tukey HSD post hoc test); however, differences of the D_0 drills from the D_20 and D_30 drills were significant (Table 2, Fig 6).

Discussion

The present experimental in vitro study unmistakably confirms that increasing drill wear, drilling pressure, and decreasing irrigation can cause substantial heat formation during bone preparation. It confirms that drills create heat during bone preparation; however, the amount of heat depends on several factors. The formation of heat has 2 main components: *1)* the cutting edges break intermolecular bonds, which release energy in the form of heat; and *2)* friction from the non-preparing surfaces of the drill (eg, the flank, flutes, and shaft) also produces heat.[6,19] Furthermore, the parameters that influence temperature during bone drilling can be divided into 2 groups: *1)* the drilling parameters (ie, drilling speed, cooling, feed rate, drilling pressure, drilling depth, and predrilling) and *2)* the drill specifications (ie, diameter, cutting face, flutes and helices, drill point, and drill wear).[7,20-22] Although many drilling parameters can easily be controlled, some factors are predetermined (such as bone cortical thickness), and some drill specifications can be ambiguous, such as extent of drill wear. In an optimal case, the surgeon knows exactly how many times the actual drill was used, or the unacceptably worn drill should be recognized according to its macroscopic appearance. Because using new drills in each patient is not feasible worldwide, the authors' intention was to examine a broad spectrum of used drills in this study (D_10 to D_30).

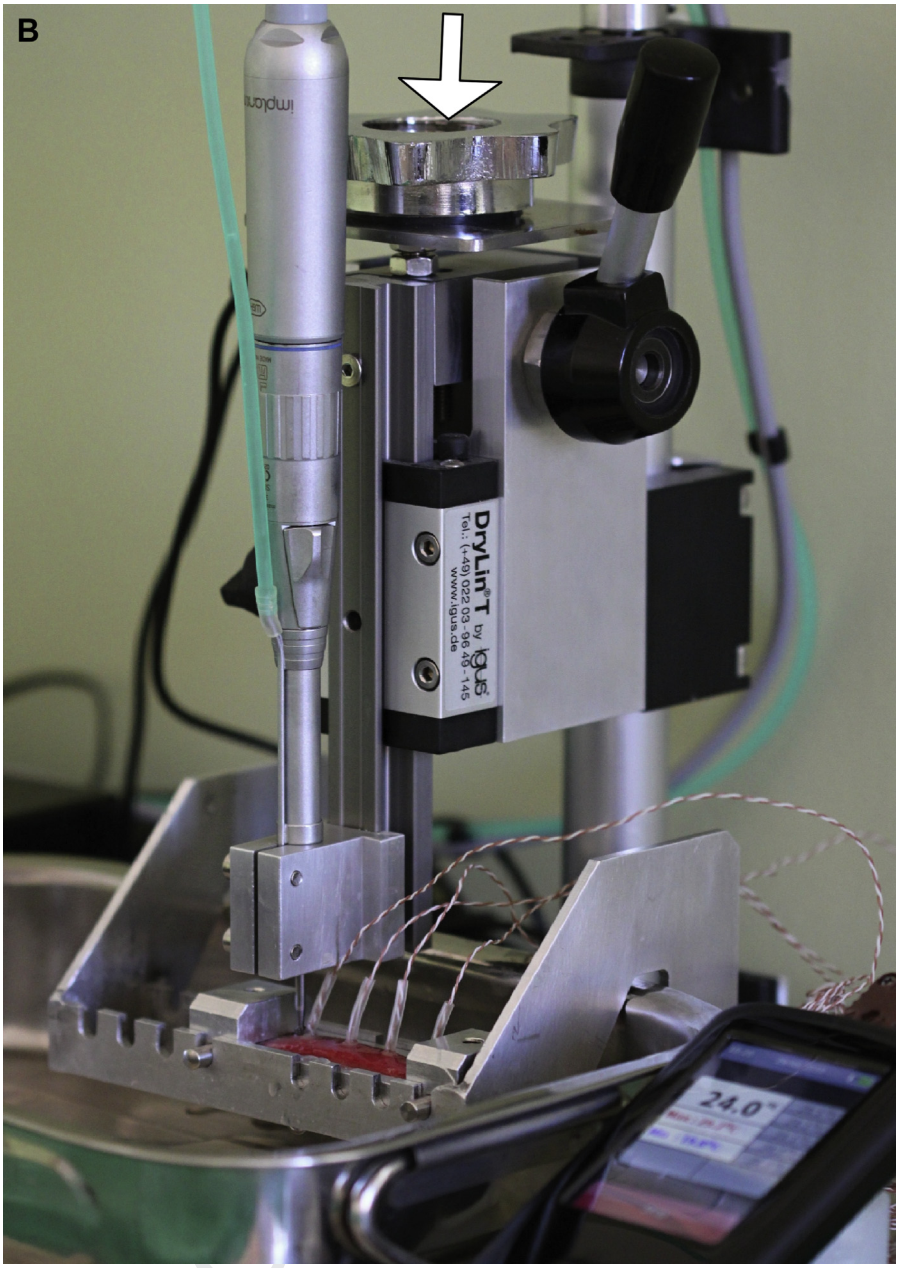

FIGURE 2 (cont'd). *B*, Platform for adjustable weights (*arrow*). **(Fig 2 continued on next page.)**

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Cortical bone thickness and bone mineral density strongly influence the duration of drilling.[6] Bovine, porcine, and canine bones are typically used in in vitro experiments; however, none of these animal models are exactly identical to the human situation.[23] The present in vitro study used pig rib bones for the investigations because of the acceptable interspecies differences in such tests.[19,23] In addition, Veli et al[24] performed a cone-beam computed tomography-based investigation and found that the human mandibular cortical thickness at the second molars is 2.11 to 3.04 mm, and Di Bari et al[25] reported comparable data from the retromolar region during graft harvesting. For these reasons, the specimens selected for the present study had cortical thicknesses of 2.1 to 2.3 mm.

According to Augustin et al,[6] the exact threshold temperature for thermal ON remains unclear; and according to Lee et al,[9] only anecdotal criteria have been suggested in the literature. It is well accepted that bone temperature should be maintained below 47°C to prevent thermal necrosis.[11] It has been proved that 90°C for only a few seconds can lead to bone necrosis (according to Berman et al,[26] this temperature is only 70°C) and that 50°C for 30 seconds can cause

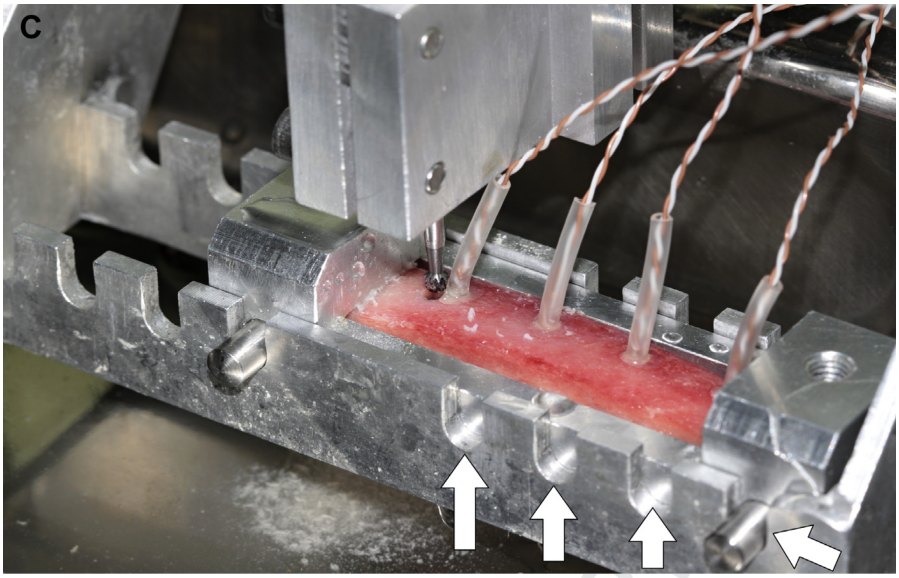

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FIGURE 2 (cont'd). *C*, The bone fixating box functioned with the drilling apparatus (*arrows* indicate the 4 predetermined locations of the box) to precisely determine the locations of bone perforations.

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irreversible enzymatic disturbances in the cortical bone.[6,12,26,27] Other investigations have shown that temperature increases of only 4.3°C cause meaningful differences in the quality of newly formed bone around an implant.[8,28] The present results indicated that after 30 coronectomies with 25-N axial loads and 20 mL/minute of irrigation, the drills produced temperatures that exceeded the 47°C limit and an average increase of 20.48°C; however, it should be noted that temperatures exceeding the threshold were never sustained for longer than 20 seconds. Nevertheless, according to the observations of Berman et al,[26] some maximum temperature increases observed in the present study (eg, 37.8°C) would equate to a temperature of 74.8°C in human environments, and these temperatures could cause bone damage after only a few seconds. Irrigation helps to dissipate heat, and the effects of lubrication further decrease friction and aid the effective removal of bone chips, which prevents clogging of the flutes, which increases heat production.[7,29] Nevertheless, decreased and compromised irrigation can occur during some retromolar manipulations when soft tissues or reduced mouth opening impair ideal access or when the drill is not in its deepest position in the handpiece and the orifice of the irrigation tube is not set well in relation to the drill's actual "working length." An impaired or obdurate irrigation channel also can decrease irrigation.

Some published reports have concluded that implant drills can be used several times without causing potentially harmful bone temperatures.[10,30,31] Furthermore, very little and minimally visible drill wear has been frequently observed in such investigations after 25,[31] 40,[32] 50,[10] or 100[30] uses and additional sterilization cycles. Allan et al[33] examined 1.5-mm-diameter twist drills and reported that 600 holes had to be drilled to elicit measurable temperature changes. In contrast, the drills in the present study exhibited obvious signs of wear after 20 and 30 coronectomies (Fig 1); however, the possible additional effects of repeated sterilizations on the sharpness of a drill's cutting edges were not investigated in that study. With worn drills, blunt cutting lips produce more friction; moreover, the elimination of heated bone chips and debris is increasingly limited, and this elimination is typically an important heat-decreasing factor despite the poor thermal capacity and conductivity of bone (bone chips carry away less heat than, eg, metal particles).[6,34] The present temperature data in relation to drill wear indicated that heat generation with mild pressure (6 N) and sufficient irrigation (60 mL/minute; adjusted for human temperatures) was below the 47°C threshold for even the most worn D_30 drills. According to Pandey and Panda,[7] independently increasing the speed or load causes increases in bone temperature. The suggested revolution rate for third molar removal is approximately 6,000 to 10,000 per minute; thus, the drilling speed was set to 8,000 per minute and kept constant in this study. Drilling pressures applied by surgeons are typically 6 N (as used in the present study) to 24 N; however, in some specialties (eg, traumatology and orthopedics), these pressures can be much higher (eg, up to ∼120 N).[7,33,35,36] The present results showed

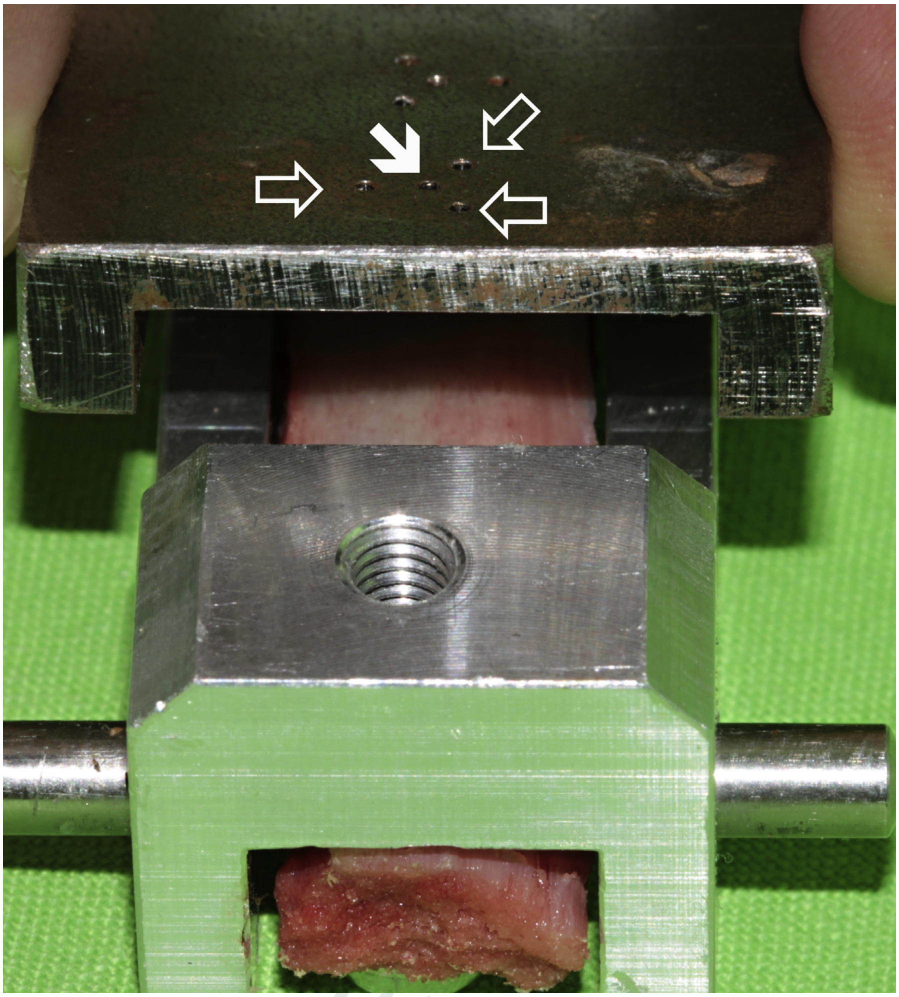

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FIGURE 3. Bone specimen in bone fixating box during metal drill guide placement. The guide indicated the exact locations of the thermocouple sensors (*open arrows*) and the subsequent cavity preparation locations (*solid arrow*).

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that the D_30 drills required preparation times that were approximately 12 times longer than those needed for new drills (31.48 vs 2.52 seconds); therefore, surgeons using worn drills might unknowingly apply greater loads to achieve more effective and more rapid drilling similar to that

Table 1. OBSERVED HEAT PRODUCTIONS AND DRILLING TIMES WITH DIFFERENT DRILLS

	Heat Production (°C)				Preparation Time (seconds)			
Drills	Mean	SD	Min	Max	Mean	SD	Min	Max
D_0	1.18	0.28	0.6	1.7	2.52	1.16	1.40	4.70
D_10	2.33	0.77	0.8	3.3	8.31	2.88	4.37	12.35
D_20	2.57	0.57	1.5	3.6	13.29	5.66	4.64	21.90
D_30	3.94	0.62	2.8	4.7	31.48	12.93	13.81	51.02
D_30_25N_60 mL/min	6.31	1.23	4.7	8.2	*			
D_30_25N_20 mL/min	20.48	8.84	11.0	37.8	*			

Abbreviations: D_0, new drill; D_10, drill after 10 coronectomies; D_20, after 20 coronectomies; D_30, after 30 coronectomies; D_30_25N_60 mL/min, drills after 30 coronectomies with 25-N axial loads and 60-mL/minute irrigation; D_30_25N_20 mL/min, drills after 30 coronectomies with 25-N axial loads and 20-mL/minute irrigation; Max, maximum; Min, minimum; SD, standard deviation.

* Drilling times were no longer than 3 seconds.

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Table 2. COMPARISONS OF DIFFERENT DRILLS USED IN THIS STUDY

	Differences in Heat Production				Differences in Preparation Time			
		95% CI				95% CI		
Comparison of Investigated Drills	Differences of Means (°C)	Lower	Upper	*P* Value*	Differences of Means (s)	Lower	Upper	*P* Value*
D_10 vs D_0	1.14	0.56	1.72	<.001	5.79	−2.13	13.71	.294
D_20 vs D_0	1.38	0.80	1.97	<.001	10.77	2.84	18.69	.010
D_30 vs D_0	2.76	2.18	3.34	<.001	28.95	21.03	36.88	<.001
D_10 vs D_20	−0.24	−0.94	0.45	.744	−4.98	−14.45	4.50	.425
D_10 vs D_30	−1.62	−2.31	−0.92	<.001	−23.16	−32.64	−13.69	<.001
D_20 vs D_30	−1.38	−2.07	−0.68	<.001	−18.19	−27.66	−8.72	<.001
D_30 vs D_30_25N_60 mL/min	−2.43	−8.05	3.19	.516	†			
D_30 vs D_30_25N_20 mL/min	−16.59	−22.21	−10.97	<.001	†			

Abbreviations: CI, confidence interval; D_0, new drill; D_10, drill after 10 coronectomies; D_20, after 20 coronectomies; D_30, after 30 coronectomies; D_30_25N_60 mL/min, drills after 30 coronectomies with 25-N axial loads and 60-mL/minute irrigation; D_30_25N_20 mL/min, drills after 30 coronectomies with 25-N axial loads and 20-mL/minute irrigation.

* Tukey honest significant difference post hoc test.

† Drilling times were no longer than 3 seconds.

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achieved with new drills. Indeed, the higher axial pressure of 25 N used in the present study considerably increased intraosseous temperatures (~6.3°C) to levels that would equate to approximately 43.3°C in humans, with such temperatures potentially being harmful to the bone.[28] In contrast, some researchers have concluded that despite higher axial pressures that result in increased friction, the heat generated in bone is decreased because shorter drilling time results in less bone exposure.[6,7] In contrast, greater higher axial forces increase the likelihood of drill breakage and increase intraosseous trauma, resulting in characteristic micro-cracks and decreased blood flow that in turn increase the frequency of the development of alveolitis.[37] However, the heat-decreasing effects of greater axial pressures (ie, increases in feed rate owing to constant drilling speed) were observed at much slower drill speeds (600 to 1,200 per minute) by Bachus et al[38] and Nam et al[39] and at much faster rotational speeds (20,000 to 100,000 per minute) by Abouzgia and Symington[40] compared with the speed of 8,000 per minute used in the present study. In contrast, these researchers investigated new drills and did not examine the role of drill wear. Moreover, most

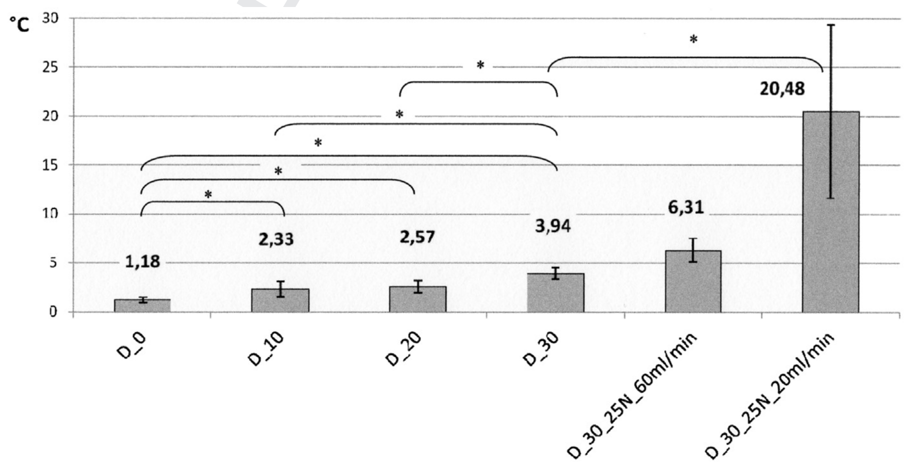

FIGURE 4. Bar chart of average intraosseous heat production values of different drills and drilling parameters. *Statistically significant differences of mean values by Tukey honest significant difference post hoc test. D_0, new drill; D_10, drill after 10 coronectomies; D_20, after 20 coronectomies; D_30, after 30 coronectomies; D_30_25N_60 ml/min, drills after 30 coronectomies with 25-N axial loads and 60-mL/minute irrigation; D_30_25N_20 ml/min, drills after 30 coronectomies with 25-N axial loads and 20-mL/minute irrigation.

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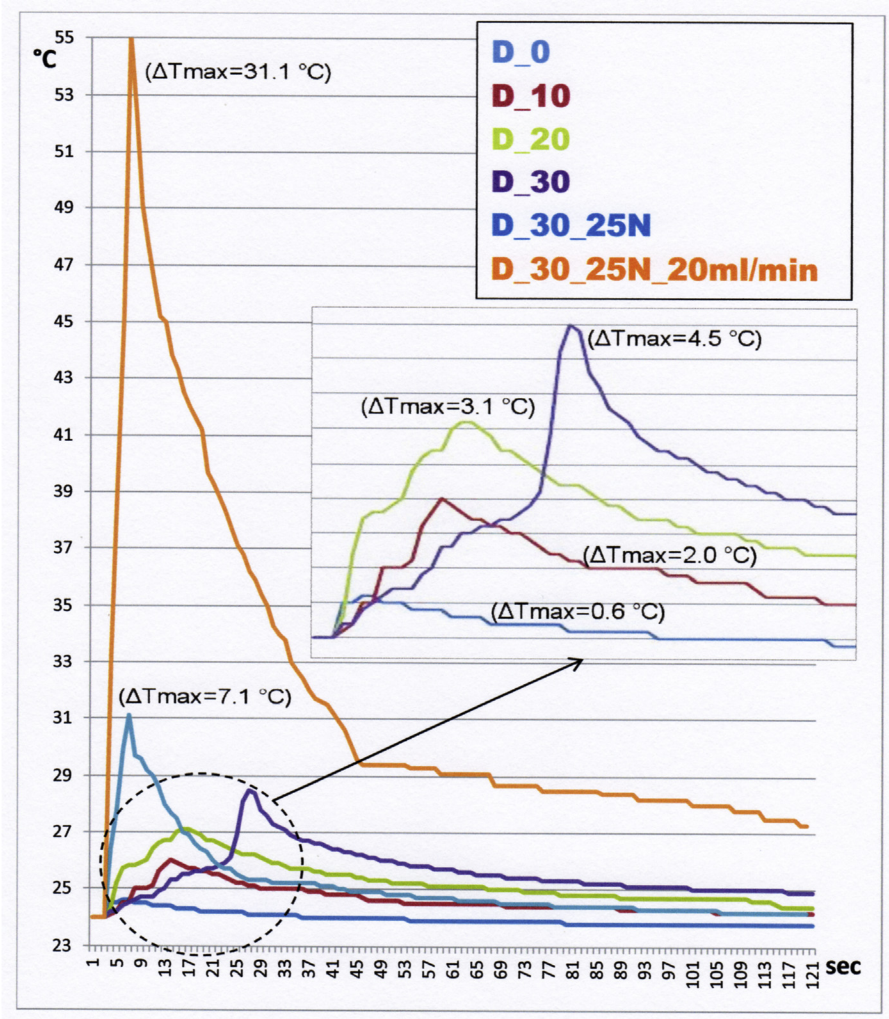

FIGURE 5. Graph representing a temperature measurement. Drills with greater amounts of wear resulted in slower temperature increases and higher peak values that were followed by slower gradual decreases in temperature. With the D_10, D_20, and D_30 drills, the temperatures did not return to the initial temperatures within 120 seconds. D_30 drills with higher pressure (D_30_25N) and decreased irrigation (D_30_25N_20 ml/min) produced considerably higher temperatures. D_0, new drill; D_10, drill after 10 coronectomies; D_20, after 20 coronectomies; D_30, after 30 coronectomies; D_30_25N, drills after 30 coronectomies with 25-N axial loads and 60-mL/minute irrigation; D_30_25N_20 ml/min, drills after 30 coronectomies with 25-N axial loads and 20-mL/minute irrigation; ΔTmax, difference in maximum temperature.

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investigations in the literature have dealt with twist drills (eg, implant bed drills, mini-implant drills, osteosynthesis drills, and orthopedic drills), so direct comparisons with the present results for round drills are difficult.

In conclusion, these findings indicate that drill wear from coronectomy procedures substantially increased heat production and drilling times. The D_30 drills prepared cavities 12 times more slowly and produced approximately 3 to 6 times more heat than the new drills. Although it has to be noted that the same degree of drill wear as observed in the defined number of coronectomies in the present study can occur after much fewer tooth removals, multiple tooth sections or more crown sections might be necessary. The heat generated with the D_0, D_10, D_20, and D_30 drills remained under the threshold level of 47°C; however, when the coolant amount was decreased to 20 mL/minute and the axial load was increased to 25 N, the average bone temperature elicited with the D_30 drills was 57.5°C, which might result in compromised bone healing after third molar removal. However, further in vivo studies are required to prove an existing correlation between heat produced by tungsten carbide round drills and clinically important defects of bone healing. In addition, future studies should focus on D_0 and D_10 drills (as the theoretical maximum wear that occurs when only 1 drill is used in 1 patient) to identify the most optimal combination of ideal axial pressures and revolution ranges during drilling.

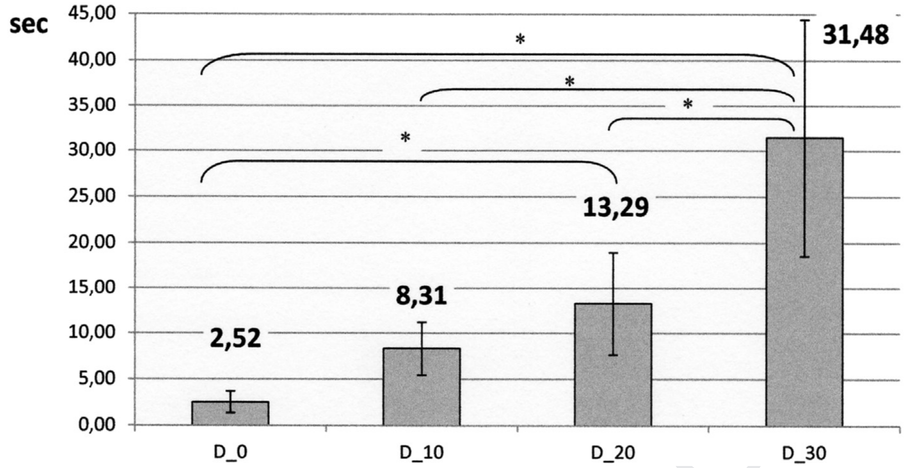

FIGURE 6. Bar chart of standardized bone cavity preparation times. *Statistically significant difference by Tukey honest significant difference post hoc test. D_0, new drill; D_10, drill after 10 coronectomies; D_20, after 20 coronectomies; D_30, after 30 coronectomies.

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