Heat and Sound Generation During Implant Osteotomy When Using Different Types of Drills in Artificial and Bovine Bone Blocks

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The purpose of this study was to compare heat and sound generated during implant osteotomy when different types of drill were used in artificial bone and bovine bone blocks. A total of 80 implant osteotomies were formed using 4 implant drilling systems: N1 (OsseoShaper) (Nobel), NobelActive (Nobel), V3 (MIS), and BLX (Straumann) in both artificial bone and bovine bone blocks. Thermocouple probes were used to record temperature change at the depths of 5.0 mm and 13.0 mm of each implant osteotomy formed by the final drill. In addition, thermographic images, drilling sound, and drilling time were recorded and evaluated. Statistical analyses were performed at $\alpha = 0.05$. The mean temperature changes as recorded by thermocouple probes and thermocamera were significantly lower in OsseoShaper than most other drill-bone combinations ($P < .05$). The mean drilling times and sound generation for OsseoShaper were significantly higher and lower than most other drill-bone combinations ($P < .05$), respectively. Minimal heat and sound generation can be expected when implant osteotomies are performed using OsseoShaper at a low rotational speed (50 rpm) even without irrigation. However, extended drilling time is required.

Key Words: heat and sound generation, implant osteotomy, different drills, artificial and bovine bone

INTRODUCTION

Minimally traumatic implant osteotomy (IO) preparation has been identified as one of the requirements for successful implant osseointegration.[1] Studies have shown excessive heat generated during IO could have negative consequences for the bone.[2] Eriksson and Albrektsson[3] determined that temperatures of 47°C or higher causes bone necrosis and inhibit bone healing. Furthermore, Matthews and Hirsch[4] detailed how temperature above 56°C during osteotomy could cause permanent injury due to denaturing of alkaline phosphatase.

The increase in temperature during IO can be attributed to drill diameter,[5] flute geometry,[6,7] and sharpness[4,8] as well as pressure,[4] depth,[5] and speed during drillig,[9,10] Other factors that also contribute to temperature change include the use of graduated vs one-step drilling,[11] intermittent vs continuous drilling,[12] internal vs external irrigation,[13,14] and variation in cortical bone thickness.[13,15] Of these, the drill geometry is the only factor not under the clinician's control. Varying results has been shown with traditional dill geometry designs with and without relief angles.[16–18] In 2019, Chen et al,[19] in a rat study, found significantly less temperature change with a mini version of a new drill design (OsseoShaper, Nobel Biocare, Göteborg, Sweden), when compared with twist drills of various diameters. To the authors knowledge, there is no study comparing the regular diameter of a new drill design (N1 OsseoShaper, Nobel Biocare) with the final drills of commonly used implant systems.

The purpose of this in vitro study was to evaluate temperature change, drilling sound and time when preparing IO with the final drill of 4 different implant systems in both artificial polyurethane bone (BA) and bovine rib bone (BB).

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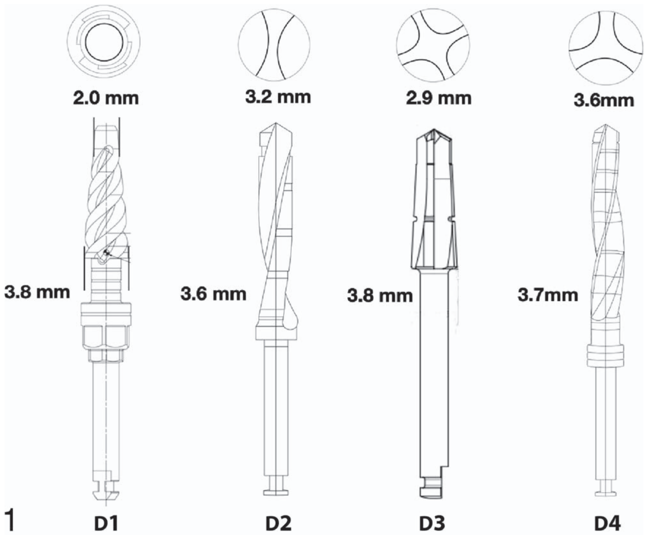
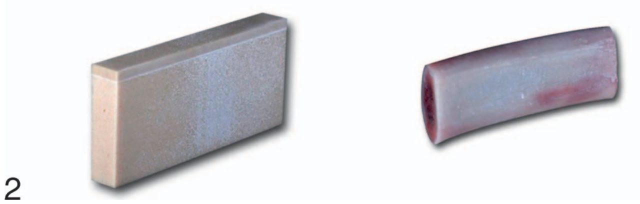
MATERIALS AND METHOD

Sequential implant drills of 4 implant systems: D1 (N1 [Nobel Biocare]), D2 (NobelActive [Nobel Biocare]), D3 (V3 [MIS Implant Technologies, Inc]), D4 (BLX [Straumann Group, Basel, Switzerland]) from 3 implant companies (Nobel Biocare, MIS Implant Technologies Inc, Straumann group) were used to prepare IO in





Figures 1 and 2. Figure 1. Cross-sectional and side views of 4 different final drills with different flute geometry, drill cutting angle and drill design. D1: N1 (OsseoShaper 3.8 mm). D2: Nobel Active (twist step drill 3.2/3.6 mm). D3: V3 (MIS conical step drill 2.9/3.8 mm). D4: BLX (Straumann X VeloDrill drill 3.7 mm). **Figure 2.** Left: Artificial bone (BA) and Right: bovine bone ribs (BB) that were used.

this study. The drilling sequence and speed were applied in accordance with the respective manufacturer's recommendation. Thermocouples (4 channel K type, AZ instrument Corp, Taiwan) and an infrared thermography camera (FLIR TG167 image thermometer, FLIR System, Inc) were used to record heat generation, while a microphone (Mic Wi436, Synthax Audio, UK) was used to record sound during IO preparation by the final drills of each implant system on both artificial polyurethane bone (BA) (Sawbones, Pacific Research Laboratories, Inc, Vashon, WA) and bovine rib bone (BB).

Types of drill

The 4 implant drilling systems with sequential drills and their respective diameters are listed below. The geometry of the final drill of each system is shown in Figure 1.

- D1 (N1, Nobel Biocare) 1. CS Pilot drill (OsseoDirector 2.0 mm), 2. Tapered drill (OsseoShaper 3.8 mm).
- D2 (NobelActive, Nobel Biocare) 1. Twist drill 2 × 15 mm, 2. Twist step drill 2.4/2.8, 3. Twist step drill 2.8/3.2, and 4. Twist step drill 3.2/3.6 mm.
- D3 (V3, MIS) 1. Pilot drill 2.0/2.4, 2. Step Drill 2.4/3.0, and 3. Conical step drill 2.9/3.8 mm.
- D4 (BLX, Straumann) 1. Needle drill, 2. X Pilot drill, and 3. X VeloDrill drill 3.7 mm.

Bone samples preparation

Forty bone samples (20 BA, 20 BB) (Figure 2) were used in this study. Each BA was prepared to a dimension of 10 × 40 × 80 mm. The BBs were purchased from a local butcher 1 day before testing. Soft tissue and periosteum were removed and were cut into 5.0-cm lengths using a Microtome (TechCut 4 Precision low speed saw, Allied HighTech Product, Inc). The BB were then secured in a vertical position using Type 4 stone (Snap-Stone, WhipMix), and were trimmed to a 20 × 30 × 50 mm dimension. The top surface of each BB was flattened for the IO. All BB were kept in a refrigerator at 0°C and stored in saline solution at room temperature for 2 hours before testing.

Two IO were prepared (randomly selected from 2 of the 4 different implant systems) 30-mm apart in each bone sample for a total of 80 sites, resulting in 10 sites for each drill-bone (DB) combination (Figure 3). The depth and distance of the thermocouples and microphone lateral to the osteotomies were standardized. Two 1.0-mm drilling channels for the placement of thermocouples, one 5-mm deep (TC1) and the

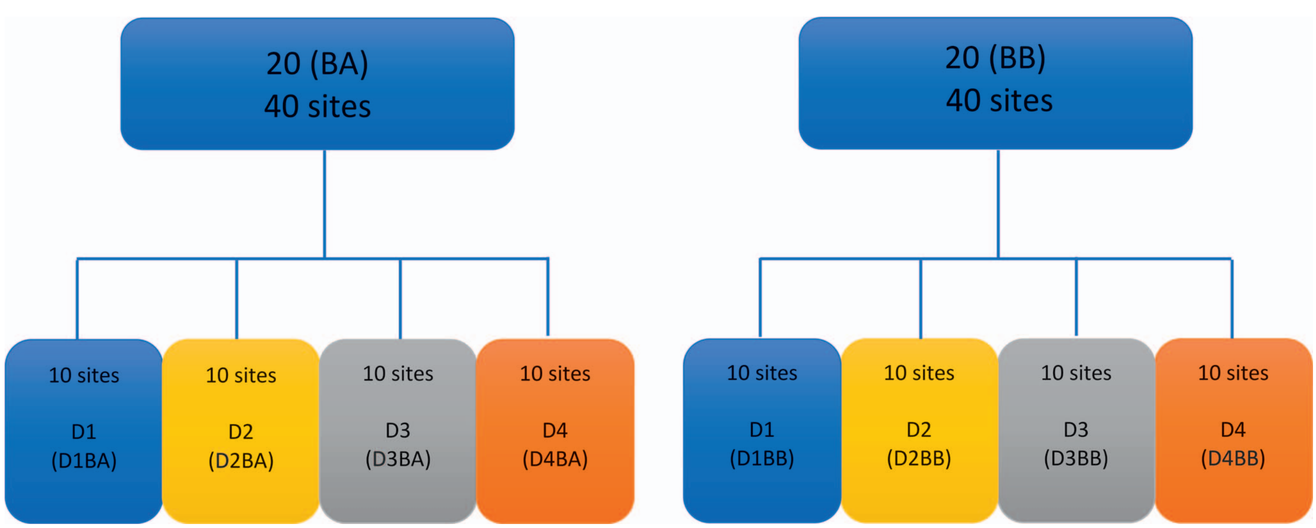
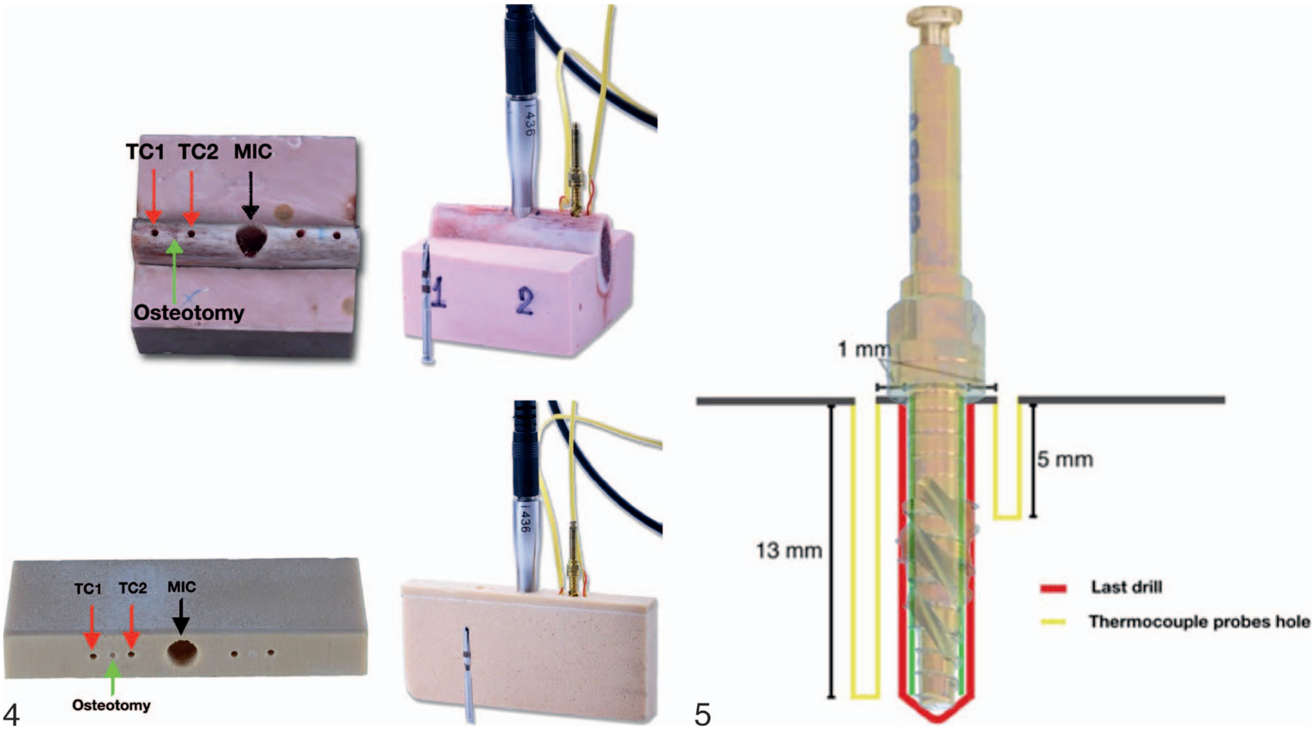


Figure 3. Diagram displaying 8 drill-bone (DB) combinations.



Figures 4 and 5. Figure 4. Preparation of depth and distance of drilling channels in BA and BB samples. **Figure 5.** Diagram illustrating drilling depth and distance of thermocouple probe holes at 5.0 mm (TC1) and 13.0 mm (TC2).

other 13-mm deep (TC2), directly opposing each other and 1.0-mm lateral to the projected IO of the final drill of each implant system. Thermocouples were placed in these channels to record bone temperatures during final IO preparations. Between the 2 planned IO on each bone sample, a 6.0-mm diameter and 7.5-mm deep channel was created for placement of the microphone to record drilling noise (Figures 4 and 5).

Experimental setup of IO

To simulate a constant load applied during IO preparation, the implant handpiece (ART surgical handpiece LCC-120A Dowell Dental Product) was mounted on a pulley system with a 1500-g weight on a vertical drill stock (Figure 6). Each IO was made under a constant load applied at rotational speeds recommended by each respective manufacturer (D1 50 rpm, D2 800 rpm, D3 400 rpm, and D4 800 rpm). Each IO was sequentially enlarged with external irrigation (30 mL/min) at room temperature, all the way to the second to the last drill. Then, each IO site was irrigated to remove debris. A brand new final drill was then used in each of the 80 IO with external irrigation (30 mL/min) in Ds 2 to 4, and without in D1 (manufacturer's recommendation).

The thermocouple probes were connected to a data acquisition unit through a 4-channel multiplexer with simultaneous channel switching every second. The temperatures were recorded at 2 depths [TC1 (5.0 mm) and TC2 (13.0 mm)] by the multiplexer unit and monitor display. The data before drilling were used as baseline temperature and were obtained for each bone sample. The temperature change (ΔT in °C) was calculated as T_1–T_0, where T_1 is the temperature during final IO preparation and T_0 is the baseline temperature of the bone samples.

Thermographic images of the drilling process were obtained using infrared thermographic camera with IR resolution of 80 $\times$ 60 pixels, image frequency of 9 Hz, and objective temperature range between -25°C and $+380$°C. The measurement accuracy was within $\pm$1.5% and the measurement distance was 10 inches. Baseline temperatures were measured before the drilling and temperature change (ΔT in °C) was calculated as T_1–T_0, where T_1 is the temperature during final IO preparation and T_0 is the baseline temperature of bone samples. The T_1 thermographic image was taken only when the drill reached its most apical position (13.0 mm) (Figure 7).

A microphone was used to record sound during IO drilling in average decibels by dB meter application (Decibel X) using a tablet (iPad Air, Version 12.0.1 (16A404), Apple). In addition, drilling time (total time to complete final IO) was recorded as a variation of each drill rotational speed.

Statistical analysis

Temperature changes (ΔT) were calculated and presented as means and corresponding standard deviations (SD). Two-way analysis of variance (ANOVA) was used between the drill groups (D1–4) and types of bone (BA, BB) for infrared thermography camera, TC1, TC2, microphone and drilling time. All data were settled for a series of Kruskal-Wallis procedures with Dwass, Steel, Critchlow-Fligner (DSCF) pairwise comparisons. All

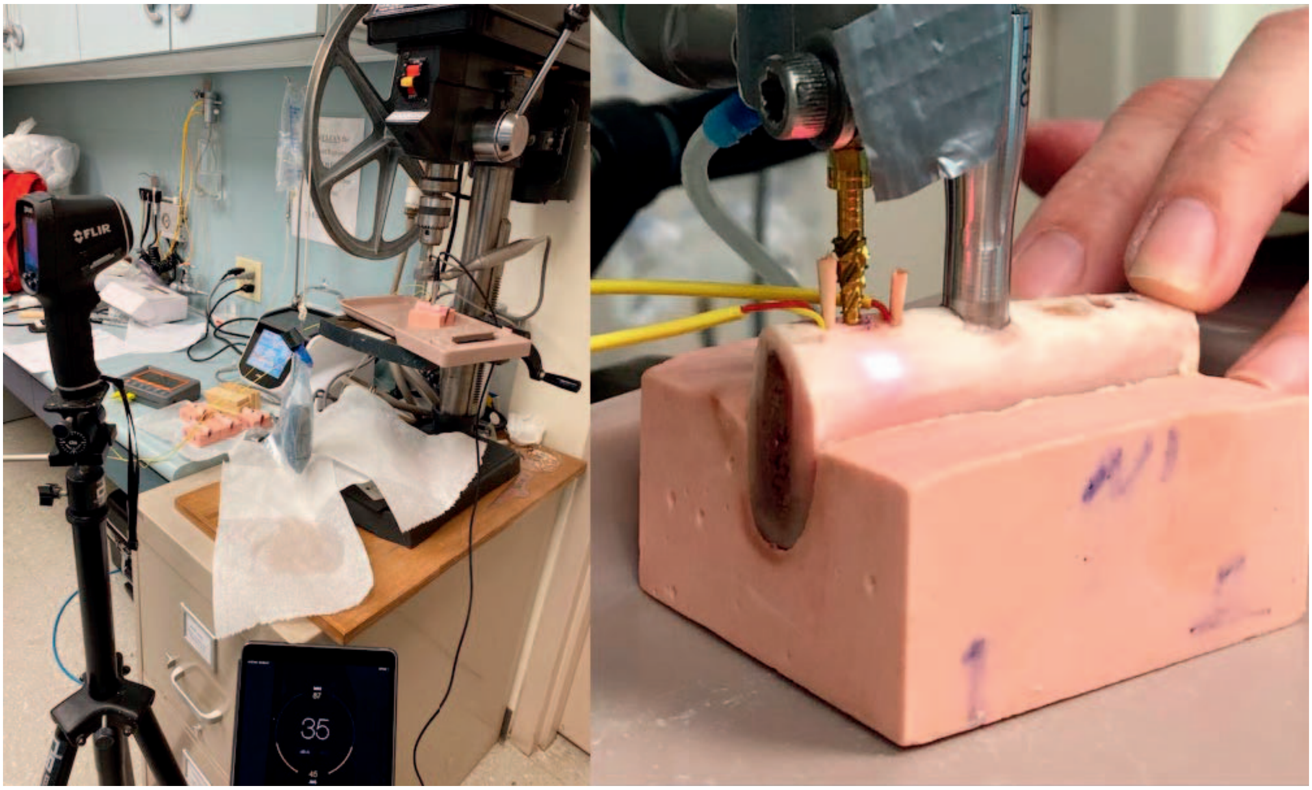


Figure 6. Experimental setup of implant osteotomy.

statistical analyses were performed using SPSS Statistics v26 (IBM Corp, Armonk, NY) at $\alpha = 0.05$. The methodology was reviewed by independent statistician.

Results

Comparisons of mean temperature change (ΔT) among Ds 1 to 4 utilizing thermocouples and thermocamera are shown in Table 1. In term of thermocouple recordings, the mean ΔT for D1 at TC1 were only significantly lower than D2BA, and D4BB ($P < .05$, Table 1) but not significantly different from other DB combinations. The mean ΔT between BA and BB at TC1 was significantly different only in D4 ($P = .009$, Table 1). At TC2, the mean ΔT for D1 was significantly lower than all DB combinations ($P < .05$, Table 1) except for D3BA and D2BB. The mean ΔT between BA and BB at TC2 was significantly different only in D2 ($P < .001$, Table 1). When comparing the mean ΔT between TC1 and TC2, the only significant difference was found in D2BA ($P = .006$, Table 2).

The recordings from the thermographic camera showed the mean ΔT for D1 were significantly lower than for all DB combinations, except for D2BA ($P < .05$; Table 1, Figure 8). The mean ΔT between BA and BB was significantly different in only D2 ($P < .001$) (Table 1).

Mean drilling times were recorded in seconds and shown in

Table 1

Comparison of mean temperature change (ΔT, °C) among different DB combinations from thermocouple (TC1 and TC 2) and thermocamera. Values are mean ± SD (N = 10)

	TC1			TC2			Thermocamera		
	BA	BB	P§	BA	BB	P§	BA	BB	P§
D 1	0 ± 0.1^{a}	-0.03 ± 0.06^{a}	.569	-0.02 ± 0.07^{a}	0.01 ± 0.03^{a}	.279	0.13 ± 0.12^{a}	0.25 ± 0.19^{a}	.113
D 2	0.62 ± 0.19^{b}	0.33 ± 0.14^{ab}	.059	0.89 ± 0.19^{b}	0.27 ± 0.29^{ab}	<.001*	0.42 ± 0.18^{ab}	1.21 ± 0.62^{b}	<.001*
D 3	0.56 ± 0.38^{ab}	0.41 ± 0.27^{ab}	.323	0.49 ± 0.37^{a}	0.59 ± 0.27^{b}	.506	0.84 ± 0.47^{b}	0.93 ± 0.38^{b}	.585
D 4	0.51 ± 0.32^{ab}	1.23 ± 0.71^{b}	.009*	0.73 ± 0.36^{b}	0.66 ± 0.51^{b}	.731	0.74 ± 0.35^{b}	0.97 ± 0.56^{b}	.272
P¶	<.001*	<.001*		<.001*	<.001*		.002*	<.001*	

a, b, c Different letters denote statistically significant difference.

*Statistically significant difference.

¶Two-way analysis of variance (ANOVA).

§Kruskal-Wallis procedures with Dwass, Steel, Critchlow-Fligner (DSCF) pairwise comparisons at $\alpha = 0.05$.

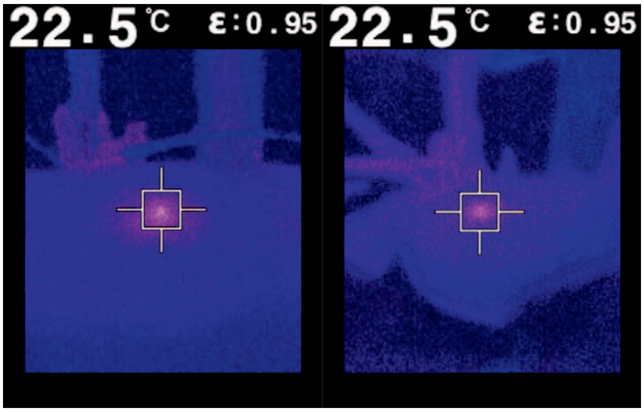


Figure 7. Infrared thermocamera images illustrating the area of maximum thermal emissionof BA (left) and BB (right) at implant osteotomy.

Table 3. Drilling time for D1 was significantly higher than all DB combinations in both BA and BB ($P < .05$; Table 3, Figure 9). The mean drilling times between BA and BB were significantly different for all DB combinations ($P < .05$; Table 3).

There were variations in sound generated during IO as recorded by microphone and shown in Table 4. The average sound produced in D1 was significantly lower than D2 and 4, but not D3 in both BA and BB ($P < .05$, Table 4, Figure 10). The average sound produced between BA and BB was significantly different in only D2 ($P = .025$) and D4 ($P = .03$) [Table 4].

Discussions

The present study compared ΔT in 4 implant drilling systems with different drill designs and flute geometries (Figure 1). Studies have shown drill design and flute geometry can affect heat generation when preparing osteotomies.[16–18,20,21] Chacon et al[16] studied the heat generated by 3 implant drill systems and found increased temperature for systems that lacked relief angles and had small clearance angles. Smaller relief angles

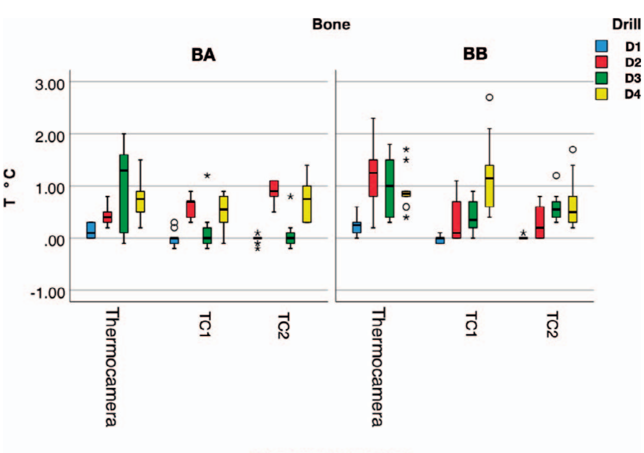
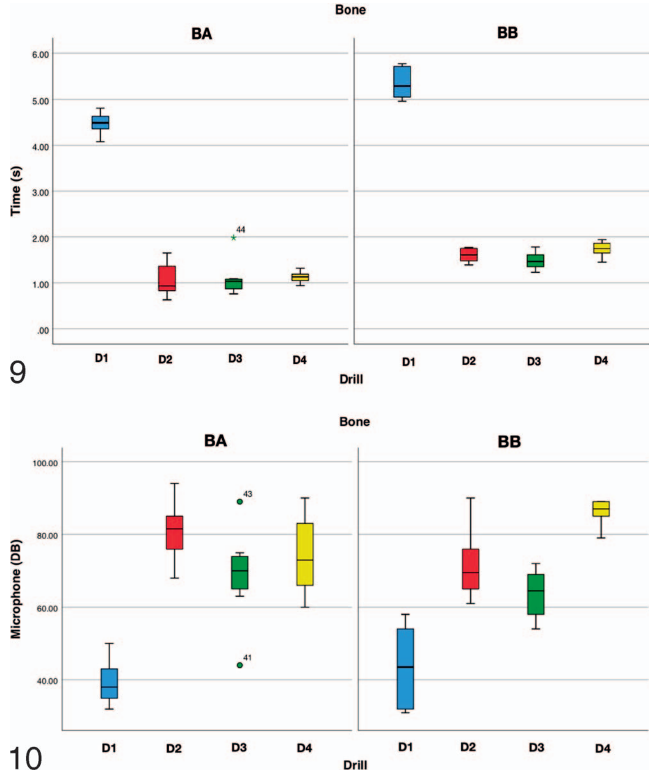


Figure 8. Boxplot of mean temperature change (°C) during IO compared between drilling groups (D1–4), measurement methods, artificial bone (BA) and bovine bone (BB).



Figures 9 and 10. Figure 9. Boxplot of mean of drilling times during osteotomy compared between drilling groups (D1–4), artificial bone (BA) and bovine bone (BB). **Figure 10.** Boxplot of mean average sound generated during osteotomy compared between drilling groups (D1–4), artificial bone (BA) and bovine bone (BB).

increase bone contact resulting in increased frictional heat. In 2010, Oh et al,[17] an in vitro study, evaluated the effects of drill-bone contact area on bone temperature during osteotomy preparation. They suggested that reduction in contact area between drill and bone reduces heat production. In 2017, Oh et al,[18] in another in vitro study, compared cutting efficacy of drills with 2, 3, and 4 flutes geometry for heat generation. They found that increasing the number of flutes increased temperature change during osteotomy, while cutting efficacy was not significantly different. From the results of the present study, the unique cutting flute geometry as well as having the smallest drill tip might contribute to the least heat generated by the N1 drill when compared with the other drills tested.

Rotational drill speed is considered as one of the most important factors that could influence heat generation during IO preparation. Most studies have been performed to investigate temperature change at a conventional speed (1000–1200 rpm) with irrigation. However, Anitua et al,[22] Kim et al,[23] and Calvo-Guirado[24] compared heat generation of low speed drilling system (50 rpm without irrigation) vs conventional drilling systems (1000–1200 rpm with irrigation) in animal bone. They found the temperature increase at the tip of the drill using a low speed system did not exceed the critical level. Chen et al[19] compared osteotomies by mini OsseoShaper (∅1.0/1.6 mm, 50 rpm without irrigation) vs conventional drill (∅ 1.6 mm, 1000 rpm with irrigation) in terms of heat generation and histology. They found the mini OsseoShaper

TABLE 2

Comparison of mean temperature change (ΔT, °C) among different DB combinations in thermocouple (TC1 and TC 2). Values are mean ± SD (N = 10)

	BA			BB		
	TC1	TC2	*P*	TC1	TC2	*P*§
D 1	0 ± 0.1[a]	−0.02 ± 0.07[a]	.712	−0.03 ± 0.06[a]	0.01 ± 0.03[a]	.107
D 2	0.62 ± 0.19[b]	0.89 ± 0.19[b]	.006*	0.33 ± 0.14[ab]	0.27 ± 0.29[ab]	.713
D 3	0.56 ± 0.38[b]	0.49 ± 0.37[a]	.685	0.41 ± 0.27[ab]	0.59 ± 0.27[b]	.163
D 4	0.51 ± 0.32[b]	0.73 ± 0.36[b]	.170	1.23 ± 0.71[b]	0.66 ± 0.51[b]	.055
P¶	<.001*	<.001*		<.001*	<.001*	

[a, b, c]Different letters denote statistically significant difference.

*Statistically significant difference.

¶Two-way analysis of variance (ANOVA) at $\alpha = 0.05$.

§Kruskal-Wallis procedures with Dwass, Steel, Critchlow-Fligner (DSCF) pairwise comparisons at $\alpha = 0.05$.

generated significantly lower peak temperatures without irrigation. In addition, their histologic results suggested that minimal temperature rise during site preparation using a low speed protocol caused fewer osteocytes to undergo programmed cell death, which translated to less peri-implant bone resorption. These results are similar to those of the present study where the mean temperature change (ΔT) in D1 (50 rpm without irrigation) was the lowest compared with the other types of drill (400–800 rpm with external irrigation) in both BA and BB samples with all measurement methods. However, D1 requires a significantly greater amount of time (3–4×) to complete the osteotomy than other systems (Table 3). Calvo-Guirado[24] reported double of time was needed for low speed protocol when compared to the conventional one.

It can be speculated that the deeper the IO, the more heat the drills may produce. Cordioli and Majzoub[5] reported a significant increase in temperature at the depths of 8.0 mm vs 4.0 mm, regardless of the drill diameter used. In contrast, a literature review by Tehemar[20] found that drilling depth was not as important a factor affecting temperature change during osteotomy as the type of irrigation used. In this study, there were no significant differences in the mean temperature change (ΔT) between TC1 and TC2 in all groups, except with D2BA (Table 2). This finding may suggest the benefit of the new design drill (D1) since it was used without irrigation.

There is currently no standardized bone model used for implant drilling research. Various animal bones (cow, pig), or artificial bone blocks (synthetic, resin) have been used.[8,17,25–31] Recently, the use of artificial bone has been widely accepted. Strbac et al[28] conducted a study using artificial bone to achieve standardization and reproducibility of the results due to the presence of a standardized ratio between cortical and cancellous bone comparable to human bone. They concluded that artificial bone has similar thermal conductivity to human bone (0.3-0.4W/m/K). Artificial polyurethane bone blocks used in this study had a 3.0-mm cortical layer to emulate bovine and human mandibular bone. When comparing the mean ΔT between BA and BB, the results from this study showed no statistically significant differences in most situations ($P > .05$); except in D4 with TC1 recordings (0.72°C), and D2 with infrared thermographic camera (0.79°C), and TC2 (0.62°C) recordings ($P < .05$; Table 1). However, these statistically significant differences (0.62–0.79°C) were not clinically significant indicating that BA can be used in place of BB.

Escalating sound produced during IO can increase patient's fear and anxiety. To date, no study has evaluated the sound generated during IO with different drill designs. This study is the first to assess sound generated during IO using a microphone. The newer design drill (D1) can decrease (dB) sound compared with the other tested drills in both BA and BB, respectively ($P < .01$). The authors propose that the use of low rotational speed (50 rpm) may be the primary reason for the lowest noise.

TABLE 3

Comparison of mean of drilling time (s) among different DB combinations (N = 10)

	BA	BB	*P*§
D 1	4.49 ± 0.21[a]	5.53 ± 0.33[a]	<.001*
D 2	1.05 ± 0.33[b]	1.59 ± 0.15[bc]	<.001*
D 3	1.07 ± 0.34[b]	1.49 ± 0.17[b]	.002*
D 4	1.12 ± 0.11[b]	1.75 ± 0.16[c]	<.001*
P¶	<.001*	<.001*	

[a, b, c]Different letters denote statistically significant difference.

*Statistically significant difference.

¶Two-way analysis of variance (ANOVA) at $\alpha = 0.05$.

§Kruskal-Wallis procedures with Dwass, Steel, Critchlow-Fligner (DSCF) pairwise comparisons at $\alpha = 0.05$.

TABLE 4

Comparison of mean of average sound generated during IO (dB) among different DB combinations. Values are mean ± SD (N = 10)

	BA	BB	*P*§
D 1	38.80 ± 5.4[a]	44.20 ± 10.02[a]	.158
D 2	80.60 ± 7.9[b]	71.70 ± 8.30[b]	.025*
D 3	68.80 ± 11.4[ab]	63.60 ± 6.20[ab]	.224
D 4	74.30 ± 10.7[b]	86.20 ± 3.00[b]	.003*
P¶	<.001*	<.001*	

[a, b, c]Different letters denote statistically significant difference.

*Statistically significant difference.

¶Two-way analysis of variance (ANOVA) at $\alpha = 0.05$.

§Kruskal-Wallis procedures with Dwass, Steel, Critchlow-Fligner (DSCF) pairwise comparisons at $\alpha = 0.05$.

Conclusions

The results of this study suggested that minimal heat and sound generation can be expected when implant osteotomies are performed using a drill of certain geometry (N1, Osseo-Shaper) at a low rotational speed (50 rpm) even without irrigation. However, extended drilling time is required.

Abbreviations

IO: implant osteotomy
D1: group 1
D2: group 2
D3: group 3
D4: group 4
BA: artificial bone
BB: bovine bone
DB: drill-bone
TC1: thermocouple 1
TC2: thermocouple 2
dB: decibel

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