Influence of the Implant Drill Design and Sequence on Temperature Changes During Site Preparation

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Purpose: *The purpose of this study was to compare bone temperature changes during implant drilling with two drill designs employed in three different drilling sequences.* ***Materials and Methods:*** *Two implant drill designs and three drilling sequences were evaluated in vitro using artificial bone cylinders. The evaluated drills were different only in the cutting-surface length (control, 16 mm; test, 4 mm). Three drilling sequences (control A, test B1, and test B2) were evaluated with and without irrigation. Temperatures were measured with thermocouple technology. The temperature changes generated by the final drill of each sequence were recorded as the experimental results and were subjected to the Student t test.* ***Results:*** *There were statistically significant differences in temperature changes when comparing the control group A with the test groups B1 (P = .001) and B2 (P = .01) during drilling without coolant. The mean temperature changes were 12.4°C, 6.5°C, and 13.7°C for groups A, B1, and B2, respectively. The Student t test showed statistically significant differences between temperature changes of the control group A and the test groups B1 (P < .01) and B2 (P < .05) during drilling with coolant. The mean temperature changes were 0.9°C, 0.7°C, and 1.9°C for groups A, B1, and B2, respectively.* ***Conclusion:*** *Reduction in length of the cutting surface of the drill may limit frictional heat. Drills with the same length of cutting surface may induce lower bone temperature changes, when considering a preliminary drilling step with a pilot drill.* Int J Oral Maxillofac Implants Implants 2015;30:351–358. doi: 10.11607/jomi.3747

Key words: *bone, dental implant, drill sequence, heat induction, implant drill, temperature changes*

In the past three decades, dental implants and surgical procedures have been developed to ensure predictable results and to improve function and esthetics.[1–5]

Implant success and survival depend largely both on the achievement of adequate healing and on the establishment of a correct osseointegration process.[6] The success of osseointegration partially depends on the state of the host bone and its healing capacity.

Drilling and trephining procedures during dental implant site preparation may cause both mechanical and thermal damage, which are critical obstacles to primary healing.[7,8] The degree of thermal injury increases exponentially with increasing temperature and exposure time.[9]

The frictional heat generated at the time of surgery can lead to a delay in bone repair due to local bone tissue necrosis, and it blocks bone microcirculation and activates bone marrow macrophages; moreover, necrotic tissue is more prone to bacterial infections.[10–13]

Eriksson, Albrektsson, and colleagues demonstrated that bone is more sensitive to heat than previously believed, and they established that the threshold level for bone survival during implant site preparation ranged between 44°C and 47°C, achieved by keeping drilling time exposure to less than 1 minute; at 50°C, the regenerative capacity of the bone was practically nonexistent.[14–16] A precise threshold temperature for thermal osteonecrosis of human bone is still unclear.[17–20] Hence, the reduction of thermal and mechanical injury during the drilling sequence plays a key role in implantology.[21–24]

Multiple factors have been implicated in the generation of heat during osteotomy preparation. These factors include drilling depth, geometry and material of the drill, sharpness of the cutting tool,[18,24] drilling speed,[25,26] pressure applied to the drill,[18] use of

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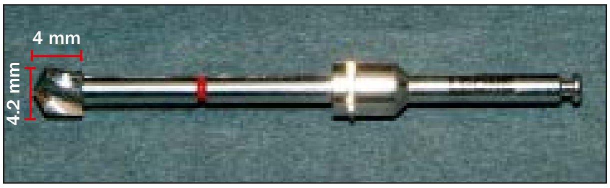

Fig 1 Test drill (4.2 Zero 1 Drill) used in the study. This drill design has a diameter of 4.2 mm and a cutting surface length of 4 mm. The sharpening of the cutting edge was similar to that of a pilot drill.

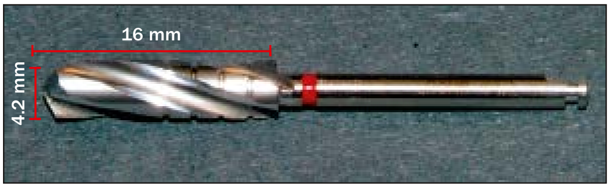

Fig 2 Control drill (4.2 Twist Standard Drill). This standard drill design has a diameter of 4.2 mm and a cutting surface length of 16 mm. The cutting edges were designed to exclusively increase the diameter of the site being drilled.

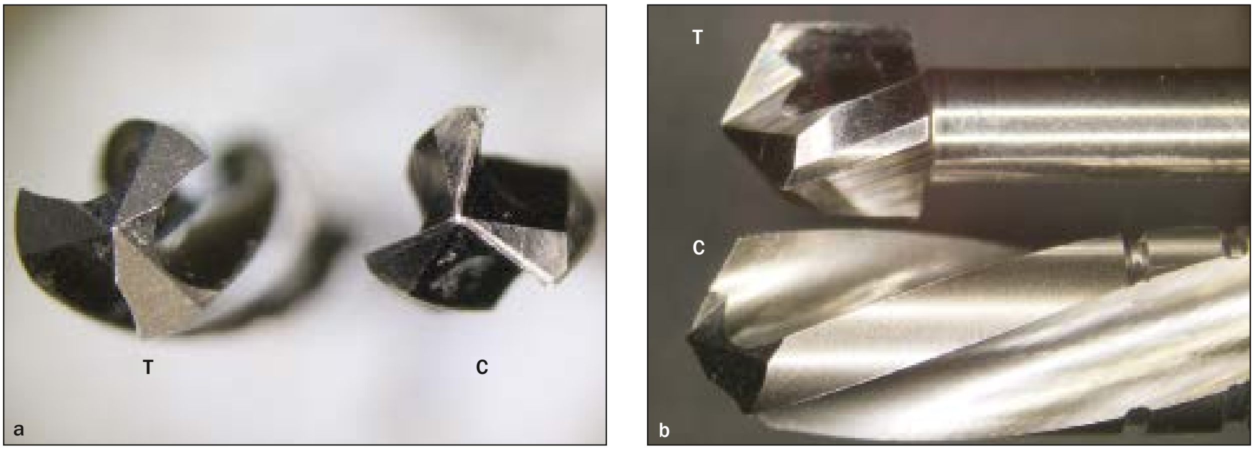

Fig 3 High-magnification images of the evaluated implant drills: T (test), 4.2 Zero 1 Drill; C (control), 4.2 Twist Standard Drill. *(a)* View from the top; *(b)* lateral view.

graduated versus one-step drilling,[15,27] irrigation,[28,29] and equipment used (motor, handpiece, power of the handpiece).[30] Moreover, heat generation varies with osteotomy location.[28,31]

Instruments used to prepare sites for implants should therefore be designed to minimize adverse effects to the implant-supporting bone.[32] Less heat generation usually accompanies drills with larger diameters compared to smaller ones. This may be the result of normally practiced graduated sequential drilling. As substantial amounts of bone have already been removed in the preceding sequences with smaller-diameter drills, larger-diameter drills are likely to cut less bone, thus resulting in smaller temperature increases.

As suggested in a previous study,[33] the reduction in bone-drill contact area reduces the heat induction during osteotomy, but this important aspect has received limited emphasis in the literature. Moreover, the ideal method for determining the bone temperature during drilling is difficult to define because bone is a complex anisotropic biologic tissue, with organic and inorganic components.[34]

The purpose of this study was to measure changes in intrabony temperature induced by two implant drills featuring different designs and, therefore, investigate the influence of the reduction in the cutting-surface length on heat generation during implant site preparation.

MATERIALS AND METHODS

Two implant drill designs were evaluated in this study. The test drill (4.2 Zero 1 Drill, Leone), designed to perform implant-guided surgery, was a cylindrical drill with a diameter of 4.2 mm, a functional length of 14 mm, an overall length of 44 mm (the drill plus the adapter/stop), and a cutting-surface length of 4 mm (Fig 1). The cutting edge was sharpened to improve the cutting power and the vertical feed (as a pilot drill). The shank of the drill, corresponding to the sleeve diameter for the surgical guides, was 2.35 mm in diameter to allow effective and easier elimination of cutting debris while reducing frictional resistance. The second drill (4.2 Twist Standard Drill, Leone), usually used to perform classic implant site preparation, was a cylindrical triflute drill with a diameter of 4.2 mm, an overall length of 39 mm, and a cutting-surface length of 16 mm (Fig 2). The cutting edges of this drill were designed to selectively increase the diameter and not the depth of the implant site during the drilling sequence. The drill material was surgical stainless steel (Fig 3). The relief, the clearance, and the rake angles of the two evaluated drills were measured with a goniometer (Fig 4).

A total of 60 artificial bone cylinders (Sawbones; 12.5 × 40 mm; density, 0.64 g/cm^3) were used to mimic type 1 bone behavior. These biomechanical test cylinders, which were used to model both cancellous and

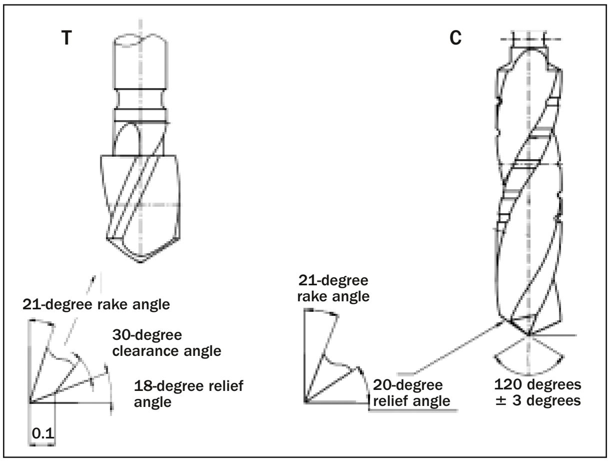

Fig 4 Computer-aided design of the evaluated drills and drill anatomy. T (test), 4.2 Zero 1 Drill; C (control), 4.2 Twist Standard Drill.

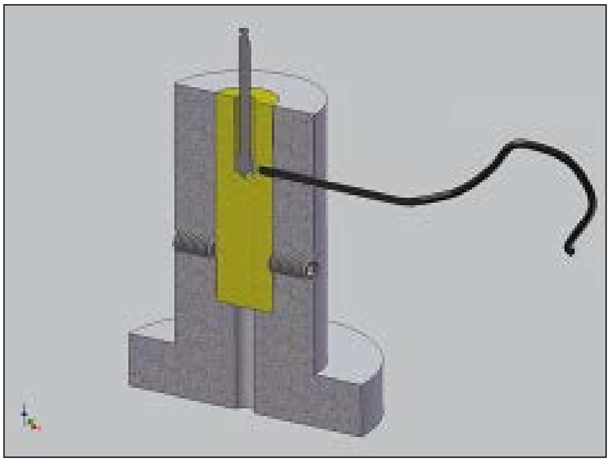

Fig 5 Three-dimensional computer-aided design of the instrument used to perform the test. The artificial bone cylinder was placed into the locking device to avoid displacement of the specimens during drilling. The thermocouple was inserted into a lateral channel in the specimen perpendicular to the long axis of the estimated drilling path. The probe was 0.6 mm away from the drill tip to avoid damage to the thermocouple.

cortical bone, offered physical properties that eliminated the variability encountered when testing human cadaver or animal bone (in reference to ASTM F-1839-08 Standard Specification for Rigid Polyurethane Foam for Use as a Standard Material for Testing Orthopedic Devices and Instruments).[33]

The bone cylinders were placed into a locking device. In the side of the locking device, a hole 2 mm in diameter was used as a guide channel, through which a lateral channel 1.7 mm in diameter was drilled into the bone cylinder. The lateral channel was positioned 13 mm from the top of the specimen (end-drilling depth = 14 mm) and perpendicular to the long axis of the estimated implant-drilling path, ie, corresponding to the final position of the drill tip being tested. The length of the channel ensured a constant distance of 0.6 mm between the thermocouple and the lateral wall of the estimated drilling path to avoid damage to the thermocouple.

The thermocouple (80PK-1 K-type, Fluke) was positioned inside the lateral channel to measure the temperature in the vicinity of the head of the channel. Furthermore, a heat-transfer compound (HTCP20S, Electrolube) was inserted between the probe and the channel (Fig 5).

A surgical micromotor (Chiropro 980, BienAir) and a contra-angle handpiece (CA30121, BienAir) with a speed-reducing factor of 30:1 were used in the drilling procedures. The torque of the micromotor was set at the maximum value, ie, without torque limitation. To provide a constant load of 30 N during drilling, an electromechanic universal testing system (Model 3365, Instron) with a load cell of 500 N was modified to accept the contra-angle handpiece (Fig 6).

Fig 6 Test apparatus. *(left)* The Instron machine for electromechanic testing was used to apply a constant load on the contra-angle handpiece, the specimen, and the digital thermocouple thermometer; *(right)* the implant motor and the saline solution.

Continuous drilling was performed to a depth of 14 mm, allowing 7.0 ± 0.1 seconds for drilling (ie, a feed rate of 2 mm/s) and 1.0 ± 0.1 seconds for staying in rotation at that depth. The total time of each perforation was controlled with a chronometer during every site preparation. The final diameter of the holes was 4.2 mm for both implant drill designs.

The drills were stored in a water bath to maintain a constant initial temperature during the tests. Four hours prior to testing, all other components required for testing were stored in a climate-controlled room (23°C to 24°C; relative humidity, 50% ± 5%; no direct ventilation on the working station). All thermal measurements were performed in the climate-controlled room. Every drill was used for one drilling procedure.

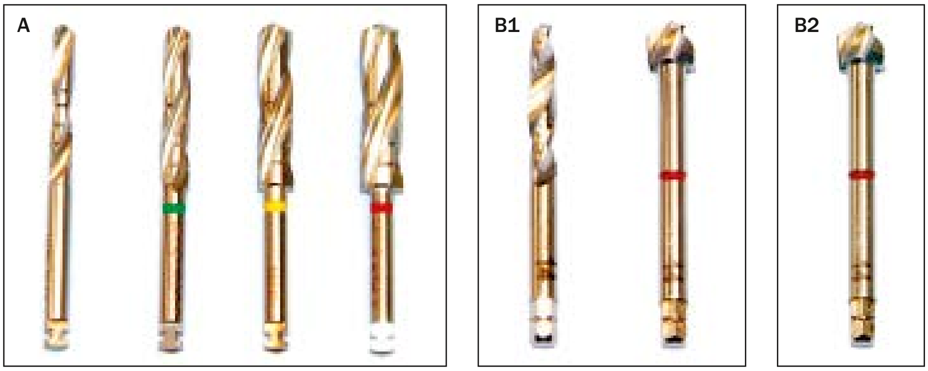

Fig 7 The three drill sequences evaluated: A, control group; B1, test group; B2, test group.

Table 1 Working Conditions of Each Tested Drill

Drill type* (diameter)	Speed (rpm)	Speed recommended by the manufacturer (rpm)	% of maximum speed
Pilot Standard (2.2)	600	800	75%
Twist Standard (2.8)	450	600	75%
Twist Standard (3.5)	375	500	75%
Twist Standard (4.2)	300	400	75%
Zero 1 (4.2)	300	400	75%
Pilot for Guided Surgery (2.35)	600	800	75%

*All drills, Leone.

Table 2 Comparison of Temperature Changes of the Six Evaluated Groups

	Without irrigation			With irrigation		
Group	A	B1	B2	A	B1	B2
Mean maximum temperature during drilling (T1) (°C)	37.4	31.5	38.8	25.9	25.7	26.9
Mean variation of temperature (ΔT) (°C)	12.4	6.5	13.7	0.9	0.7	1.9
SD of temperature variations (°C)	0.3	0.5	0.8	0.2	0.2	0.8

The first test was performed without a coolant to achieve standard conditions and an explicit comparison between the drill designs.

Three drilling sequences were evaluated to simulate three clinical scenarios (Fig 7):

- Group A (control): traditional implant site preparation; 2.2 Pilot Drill, 2.8, 3.5, and 4.2 Twist Standard Drill (standard sequence)
- Group B1 (test): guided surgery; 2.35 Pilot Drill (Leone) and 4.2 Zero 1 drill (recommended sequence for dense bone)
- Group B2 (test): guided surgery; 4.2 Zero 1 drill (recommended sequence for normal bone)

Next, the tests were performed again with an external irrigation system. Normal saline solution at room temperature was used to irrigate the site and was maintained continuously throughout drilling at a variable rate.

All osteotomies were performed according to the manufacturer's operating manual and were controlled by the same operator (GS) (Table 1). After every osteotomy the drill was placed in the osteotomy site, and a radiograph was taken to confirm the site of the thermocouple in relation to the drill.

The intrabony temperature increase generated by the final drill of each sequence was recorded as the experimental result. The variation of intrabony temperature (ΔT) was calculated by subtracting the maximum temperature reached during drilling (T1) with the bone specimen baseline temperature (T0) before each perforation, ie, $\Delta T = T1 - T0$.

Statistical Analysis

The statistical hypotheses concerning the rationale of the study were the following:

- As the contact area between the drill and bone is reduced by using a shortened cutting surface, less frictional heat is expected.
- A multiple-step drill sequence induces less heat than a single-step drill sequence.

The present study concerns the comparisons between intrabony temperature increases induced by the 4.2 Twist Standard Drill when used in its typical sequence (control group A) and the 4.2 Zero 1 drill when used in two different sequences:

- With the preliminary step of the pilot drill (test group B1)
- Without the preliminary step of the pilot drill (test group B2)

Because the tests were first performed without, and then with, irrigation, there were two independent experimental and statistical studies. According to the

Table 3 Intrabony Temperature Increases Induced by the Last Drill of the Sequences Evaluated During Osteotomies Without Irrigation, and Statistical Analysis

	Intrabony temperature increase ΔT (°C) without irrigation			Contrasts	
Replications	Group A 4.2 Twist Standard Drill (control)	Group B1 4.2 Zero 1 Drill (test)	Group B2 4.2 Zero 1 Drill (test)	Comparisons group A to group B1	Comparisons group A to group B2
1	12.4	6.5	13.2	5.9	–0.8
2	12.6	7.3	14.1	5.3	–1.5
3	12.8	6.3	14.6	6.5	–1.8
4	11.8	6.6	12.3	5.2	–0.5
5	11.9	5.9	14.9	6.0	–3.0
6	12.2	6.7	13.7	5.5	–1.5
7	12.5	6.4	13.9	6.1	–1.4
8	12.1	7.2	13.7	4.9	–1.6
9	12.8	6.4	12.2	6.4	0.6
10	12.4	5.7	14.8	6.7	–2.4
			Mean	5.85	–1.39
			SD	3.285	8.949
			Degrees of Freedom	9	9
			Standard Error	0.1911	0.3153
			Student *t* test (*t* and *P* values)	30.62 .001	–4.41 .01
			Skewness	–0.168	0.491
			Kurtosis	–1.233	1.007
			Kolmogorov–Smirnov test (D_n and *P* values)	0.133 .20	0.204 .20

drilling conditions (without and with irrigation) and the number of the comparisons for each, four linearly independent contrasts without interactions were analyzed.

It is important to note that the only variable element in the tests performed and in the recorded temperatures was the design of the drill. In this situation the block design of the results (temperatures) was very suitable to the inferential analysis. The comparison was made in each block (ΔT group A to ΔT group B1; ΔT group A to ΔT group B2), analyzing a single distribution of the results, ie, the average of the blocks through the Student *t* test. Statistical calculations were performed with the statistical software SPSS 14 for Windows (SPSS). To validate the choice about the significance test, the corresponding measures of skewness and kurtosis as well as the Kolmogorov-Smirnov test and its associated *P* value were reported. For this experimental model, closed testing procedures were not carried out because, in the absence of multiple tests, the hypothesized inferences could not control the Familywise Error Rate (FWER), in α level.

RESULTS

The examination of response time by the customized heat element showed that the transfer of heat from the element to the thermocouple took about 0.5 to 1 second. The temperature increased in all groups.

Table 2 shows the mean baseline bone temperature (T0), the mean maximum temperature recorded in the bone during drilling (T1), the mean variation of temperature (ΔT), and the related standard deviations (SDs) of each group (control group A, test groups B1 and B2) in the drilling sequences performed without and with irrigation. There were statistically significant differences in temperature increases when comparing control group A with test groups B1 ($P = .001$) and B2 ($P = .01$) during drilling without irrigation (Table 3). The Student *t* test results showed that there were statistically significant differences between the temperature increases of control group A and test groups B1 ($P = .01$) and B2 ($P = .05$) when drilling with irrigation (Table 4).

DISCUSSION

The purpose of this study was to evaluate the intrabony temperature increases with two different stainless steel drills focusing on the contact area between the drill and bone. The 4.2 Zero 1 drill is equivalent to the 4.2 Twist Standard drill in term of material, indications, and diameter, but differs in the design principles. The 4.2 Zero 1 drill has a cutting surface 4 mm in length, which provides a reduction in the bone-drill contact area during the vertical feed, ie, the osteotomy.

Table 4 Intrabony Temperature Increases Induced by the Last Drill of the Sequences Evaluated During Osteotomies with Irrigation, and Statistical Analysis

Replications	Intrabony temperature increase ΔT (°C) with irrigation: Group A 4.2 Twist Standard Drill (control)	Group B1 4.2 Zero 1 Drill (test)	Group B2 4.2 Zero 1 Drill (test)	Contrasts: Comparisons group A to group B1		Comparisons group A to group B2	
1	0.7	0.9	1.1	–0.2		–0.4	
2	0.8	0.6	0.5	0.2		0.3	
3	1.1	0.5	1.9	0.6		–0.8	
4	0.9	0.6	2.3	0.3		–1.4	
5	0.9	0.6	1.7	0.3		–0.8	
6	1.0	0.7	2.5	0.3		–1.5	
7	1.2	1.1	2.0	0.1		–0.8	
8	0.8	0.5	5.9	0.3		–5.1	
9	0.7	0.7	1.1	0.0		–0.4	
10	1.2	0.9	3.1	0.3		–1.9	
			Mean	0.22		–1.28	
			SD	0.416		19.776	
			Degrees of Freedom	9		9	
			Standard Error	0.068		0.4687	
			Student *t* test (*t* and *P* values)	3.25	.01	–2.73	.05
			Skewness	0.406		–2.147	
			Kurtosis	1.25		5.636	
			Kolmogorov–Smirnov test (D_n and *P* values)	0.255	.07	0.24	.10

As shown in a previous study, the drill material seems to not be the predominant factor influencing the frictional heat.[26,32] In contrast, Oliveira et al showed that drill design and material composition (ceramic and stainless steel) had a statistically significant influence on the overall recorded temperature increase when employed with the same standardized drilling protocol.[17]

Regarding the implant drill design and geometry, Oh et al suggested that reduction in contact area between the drill and bone reduced heat induction.[33] However, the impact of drill design in published studies is controversial.[8,22,31,35,36]

The short cutting surface of the 4.2 Zero 1 drill may be advantageous for several reasons. Many bone chips are typically formed during the drilling procedure. The flutes of the drill ensure that these chips are channeled, clearing the cutting edge and maintaining the cutting power.[35] In the 4.2 Zero 1 drill, the presence of short flutes due to its reduced length might suggest that *(1)* a smaller contact area with the bone chips could cause less frictional resistance and production of heat, and *(2)* the removal of the debris could be facilitated, avoiding the clogging of the flutes.[33]

Because of the short cutting surface, the third coronal of the implant site being prepared by the 4.2 Zero 1 drill is exposed to friction for a shorter time compared to a traditional drill featuring a long cutting surface, such as the 4.2 Twist Standard drill. Furthermore, the smaller diameter of the coronal portion of the 4.2 Zero 1 drill due to the presence of the shank creates a more favorable receptacle for the coolant. These features could lead to a lower risk of bone resorption at the implant neck area immediately after placement.

Sener et al in their study found that the highest temperature increases during drilling were in the superficial aspects of the drilling cavity, owing to the effects of the compact and spongy components of bone.[28] Their results showed that heat production is directly proportional to the time of exposure to frictional forces. This is easily explainable for two aspects concerning different bone structures. Cortical bone, the initial layer in which drilling occurs, especially in type 1 bone, is stronger and has a higher coefficient of friction compared with cancellous bone. Furthermore, the cortical layer requires prolonged drilling and the application of greater force, which produces different degrees of friction compared to inner layers of bone; furthermore, these inner layers of bone would be subjected to frictional forces for a shorter time.

Some authors, however, concluded in their studies that at increased drilling depths, higher temperatures may be expected, probably because of the inability to maintain correct levels of irrigation solution at higher depths.[17,28,35,37]

In this study, the use of the 4.2 Zero 1 drill always induced lower bone temperature increases than the 4.2 Twist Standard Drill, in the comparison of group A to group B1. In the test without irrigation, these findings (ΔT group A, 12.4°C; group B1, 6.5°C) may depend on the retrograde bone removal, which, with the 4.2 Zero 1 drill, occurs more quickly because of the reduced length of the cutting surface. Use of the 4.2 Twist Standard drill could lead to channels that are more clogged with cutting debris because of its longer flutes. In the tests performed with irrigation, the discrepancy between the temperatures obtained was much less evident (ΔT group A, 0.9°C; group B1, 0.7°C). This could be related to the filling by the coolant of the natural receptacle created by the smaller diameter of the shank of the 4.2 Zero 1 drill in the third coronal of the implant bed. This filling may act as a barrier that does not allow new coolant to reach the apical area where the cutting occurs. Conversely, the 4.2 Twist Standard drill has flutes closer to the coolant source, which may allow it to channel and guide the coolant to the tip. To achieve the same temperature increase observed in the test performed without irrigation, it would be advisable to have a significant amount of irrigation and/or a low-temperature irrigation solution when using the 4.2 Zero 1 drill.[38,39]

In these comparisons (group A to group B1), the results acquire greater relevance when considering that the two evaluated drills, 4.2 Twist Standard Drill (group A) and 4.2 Zero 1 drill (group B1), are preceded by pilot drills of 3.5 mm and 2.35 mm in diameter, respectively.

In the other two comparisons (group A to group B2, without and with irrigation) the 4.2 Zero 1 drill always resulted in temperatures higher than those of the 4.2 Twist Standard Drill. This was easily foreseeable because the 4.2 Zero 1 drill, without the preliminary step of any pilot drill, should remove greater amounts of bone than the 4.2 Twist Standard drill, preceded by the 3.5 Twist Standard Drill. Nevertheless, the temperatures were not greatly different, considering that group B2 includes only one drill in its sequence compared to group A, which consists of four drills.

In the tests performed with external irrigation, only a slight increase in the mean temperature variation was induced when the 4.2 Zero 1 drill was used without a pilot drill in group B2 (ΔT group B1, 0.7°C; group B2, 1.9°C). According to this result, the use of a pilot drill in areas of type 3 bone could be theoretically unnecessary, at least regarding the risk of bone necrosis. The data from the tests performed without a coolant are more interesting. In fact, the preliminary step of the pilot drill used in group B1 resulted in a mean temperature variation induced by the 4.2 Zero 1 drill that was 7.2°C less than that of group B2 (ΔT group B1, 6.5°C; group B2, 13.7°C). As a consequence, in type 1 bone regions, the use of the 2.35 Pilot Drill before the 4.2 Zero 1 drill should be mandatory.

Direct and indirect methods are commonly used to record temperature rise during drilling. In this study, the temperature assessment was made using one thermocouple positioned close to the tip of the drill at a constant distance of 0.6 mm between the thermocouple and the lateral wall of the estimated drilling path to avoid damage to the probe. The use of one thermocouple is as reliable as that of two thermocouples, as suggested by the similar results of various reports.[16,18,22–24,36]

Drill wear seems to play a major role in the generation of intrabony heat. It is well established in the literature that repeated bone drilling causes extensive wear on commonly used stainless steel drills, resulting in increased heat generation.[23,24] To minimize and possibly eliminate the drill-wear effect, in the present investigation, every drill was used for just one drilling procedure.

In all three groups, the mean temperature increases recorded during the osteotomies were always higher than the baseline bone temperature and less than the critical harmful threshold. Therefore, the test sequences (groups B1 and B2) may still provide equally safe methods of site preparation if the recommendations of the manufacturers are followed.

In this regard, it should be noticed that the use of the 4.2 Zero 1 drill is limited to guided-surgery procedures, and it is not suitable to all clinical uses. Because it features a cutting tip and a smooth shank, in order to produce cylindrical bores, a sleeve to guide this type of drill is necessary. The use of a sleeve may reduce the amount of irrigation, leading to an increase in heat generation. However, the data, especially the data generated from the test performed without irrigation, further emphasize this new design.

There were statistically significant differences in temperature increase when comparing control group A with test groups B1 ($P = .001$) and B2 ($P = .01$) during drilling without irrigation (see Table 3). These findings support the conclusion that the 4.2 Zero 1 drill of the first test group (Group B1) induces systematically less heat than the standard drills.

The Student *t* test showed that there were statistically significant differences between the temperature increase of control group A and test groups B1 ($P = .01$) and B2 ($P = .05$), when drilling with irrigation (see Table 4).

The Kolmogorov-Smirnov statistics and its associated *P* values further confirm the convergence in normal distribution of the empiric values (indirect confirmation of the validity of use of the Student *t* test).

CONCLUSIONS

Within the limitations of this study, it is possible to conclude that reduction in the length of the cutting surface of the drill may reduce frictional heat induction. The preliminary step of a pilot drill is crucial for the reduction of frictional heat generation, regardless of the drill geometry. In all the drill sequences evaluated, the temperatures recorded during the osteotomies were always below the critical harmful threshold for the bone, both without and with irrigation. Therefore, the tested drill sequences may be safe and reliable methods in addition to the conventional sequence.

ACKNOWLEDGMENTS

The authors reported no conflicts of interest related to this study.

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