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Implant Drill Characteristics: Thermal and Mechanical Effects of Two-, Three-, and Four-Fluted Drills

Hyun Jun Oh, DDS, MS[1]/Beom Ik Kim, BSD, MS[2]/Hae-Young Kim, DDS, MSD, PhD[3]/
In-Sung Yeo, DDS, MSD, PhD[4]/Ulf ME Wikesjö, DDS, DMD, MSD, PhD[5]/Ki-Tae Koo, DDS, PhD[6]

Purpose: *Avoiding excessive trauma—thermal or otherwise—during dental implant site preparation is considered critical to implant success; overheating is considered to be a major cause of bone necrosis. Studies evaluating thermal and mechanical effects of implant drill design are limited, and effects of flute design have not been accounted for. The purpose of this study was to compare heat generation and cutting efficiency associated with two-, three-, and four-fluted implant drills to investigate the optimal number of flutes.* ***Materials and Methods:*** *Two-, three-, and four-fluted dental implant drills with identical point, relief, and rake angles and otherwise standard dimensions were evaluated. Real-time temperature changes while drilling artificial bone were recorded using an infrared thermal imager. Cutting efficiency was assessed as the drilling time to a 15-mm depth under constant load using a specially designed recording system. Each drill variation was examined 20 times. A one-way analysis of variance was used for statistical analysis.* ***Results:*** *Mean temperature increases amounted to 8.3°C, 10.8°C, and 15.1°C for two-, three-, and four-fluted drills, respectively; temperatures significantly increased ($P < .001$) with an increased number of flutes. Mean drilling time serving as a measure of cutting efficiency amounted to 2.6, 2.5, and 2.5 seconds for the two-, three-, and four-fluted drills, respectively. A trend of cutting efficiency increasing or decreasing according to the number of flutes was not observed. Differences in cutting efficiency among the three drill variations were statistically significant ($P = .015$). The cutting efficiency of the three-fluted drill was superior to that of the two-fluted drill ($P = .016$).* ***Conclusion:*** *Within the limitations of the study, a two-fluted drill would be preferred for osteotomy preparation due to its level of heat generation, whereas a three-fluted drill showed favorable cutting efficiency.* INT J ORAL MAXILLOFAC IMPLANTS 2017;32:483–488. doi: 10.11607/jomi.4819

Keywords: *cutting efficiency, drill geometry, frictional heat, implant drill design*

Optimal bone healing with osseous integration of a dental implant may be achieved if certain surgical and biologic parameters are strictly followed.[1] Avoiding excessive trauma—thermal or otherwise—during dental implant site preparation is considered critical to implant success; overheating is regarded as a major cause of bone necrosis.[2–4] Exposure to a temperature of 47°C for 1 minute during osteotomy preparation is thought to represent an upper threshold for bone survival.[5,6]

Drill design and flute geometry are considered important factors affecting heat generation at dental implant site preparation.[7,8] The flutes of a drill are designed to remove debris from the tip as it cuts; ideally, they allow debris to escape through the channels. It has been proposed that a maximum of three drill flutes can be used without technical complications.[9] The rationale for the design of the tri-spade drill was a tripod's inherent stability and self-centering nature, suggesting a drill having three cutting edges and flutes. Thus, it was assumed, three blades and flutes were optimal since greater numbers of flutes would reduce debris escape and also aid with stability.

[1]Graduate Student, School of Dentistry, Seoul National University, Seoul, Korea.
[2]Senior Research Engineer, Osstem Implant Co, Busan, Korea.
[3]Associate Professor, Department of Health Policy and Management, College of Health Sciences & Department of Public Health Sciences, Graduate School, Korea University, Seoul, Korea.
[4]Associate Professor, Department of Prosthodontics and Dental Research Institute, School of Dentistry, Seoul National University, Seoul, Korea.
[5]Professor, Laboratory for Applied Periodontal & Craniofacial Regeneration (LAPCR), Departments of Periodontics and Oral Biology, Georgia Regents University College of Dental Medicine, Augusta, Georgia, USA.
[6]Associate Professor, Department of Periodontology and Dental Research Institute, School of Dentistry; Director, Translational Research Laboratory for Tissue Engineering (TTE), Seoul National University, Seoul, Korea.

Correspondence to: Dr Ki-Tae Koo, Department of Periodontology and Dental Research Institute, School of Dentistry, Translational Research Laboratory for Tissue Engineering (TTE), Seoul National University, 28 Yongon-Dong, Chongno-Ku, Seoul 110-749, Korea. Fax: +82-2-744-0051. Email: periokoo@snu.ac.kr

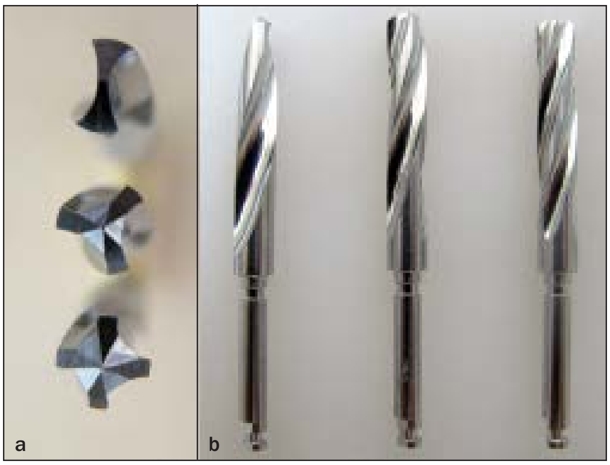
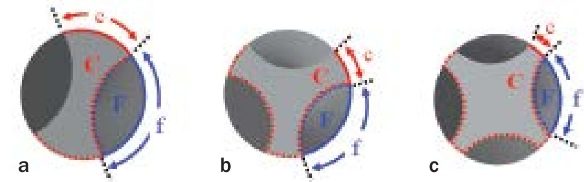


Fig 1 Evaluated drill designs. *(a) Top to bottom:* apical view of the two-, three-, and four-fluted drills. *(b) Left to right:* lateral view of the two-, three-, and four-fluted drills.



Drill	Two-fluted	Three-fluted	Four-fluted
C (mm^2)	4.5	4.6	5.5
c (mm)	2.2	1.1	0.5
F (mm^2)	2.9	1.9	1.2
f (mm)	3.4	2.7	2.3

C = area of cutting edge; F = area of flute.

Fig 2 Schematic of the drill frontal views. C = the frontal contact area; c = the arc length including C; F = the area of a flute; f = the arc length including F for *(a)* two-fluted, *(b)* three-fluted, and *(c)* four-fluted drills, respectively.

The influence of the number of drill flutes on temperature elevation has been evaluated in orthopedic settings.[10] Cutting efficiency of three-fluted drill designs was found to be superior to that of two-fluted designs, but this apparently does not translate to decreasing temperatures generated during drilling. This may be due to the fact that other variables in drill design, such as point, relief, or rake angles, were not standardized and could have affected the outcomes. In addition, evaluated drills used for orthopedic indications may have inflicted much greater load compared to those used for dental implant site preparation, keeping temperatures at higher levels.

The postulated advantages of an extra flute were that it could enhance cutting efficiency, reduce drilling time, and reduce heat generation. Apart from the theoretical advantage three-fluted drills would have over two-fluted drills, evidence of this is sparse in the biomedical literature. Four-fluted drills also need to be evaluated. However, additional flutes in the design may narrow the channels of the flutes, which serve as a pathway for debris escape. As effective elimination of bone chips is hampered, chips accumulated in the channels may impair cutting efficiency and elevate frictional heat. Yet no evidence in the biomedical literature supports this. Thus, research on the number of flutes and their effect on cutting efficiency and generation of frictional heat is necessary. The purpose of this study was to investigate cutting efficiency and heat generation associated with two-, three-, and four-fluted dental implant drills.

MATERIALS AND METHODS

Drill Design

Design of the two-, three-, and four-fluted 3.6-mm-diameter dental implant drills (Osstem Implant) produced for this study is shown in Figs 1 and 2. The design of the point, rake, and relief angles was identical for the three drill variations: 118 degrees, 15 degrees, and 14 degrees, respectively. Thus, the only difference among the drills was their number of flutes.

Temperature Measurement System Configuration

The device used for temperature assessments was consistent with the authors' previous study.[11] The overall experimental setup included the three drill variations, artificial bone blocks with a uniform platform (Sawbone, Pacific Research Laboratories), a drilling system (Hangil), and an infrared thermal imager (TVS-200EX, NEC). The bone blocks were composed of solid rigid polyurethane foam block (3 mm thick) to mimic the cortical bone, while solid rigid polyurethane foam sheets (greater than 25 mm thick) were used to model the cancellous bone. The bone blocks were soaked in a water bath at 37°C during temperature assessments to model a moist oral environment. The laboratory temperature was kept at 30° ± 1°C. Temperature changes were assessed using the thermal imager (range, –20°C to 500°C; sensitivity, 0.08°C; accuracy, 2°C). The 15-mm drilling depth was divided into six areas of interest, each measuring ∅ 3.6 × 2.7 mm. Drilling was performed

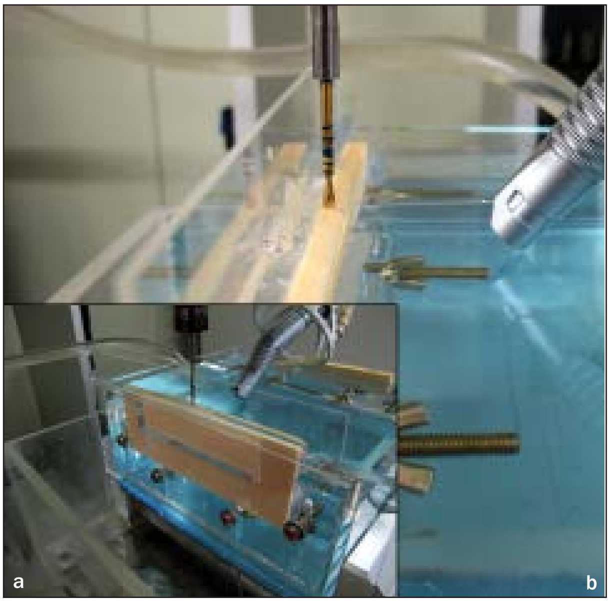


Fig 3 Irrigation device. *(a)* View of the coolant on working during drilling. *(b)* A magnified view of the coolant during drilling.

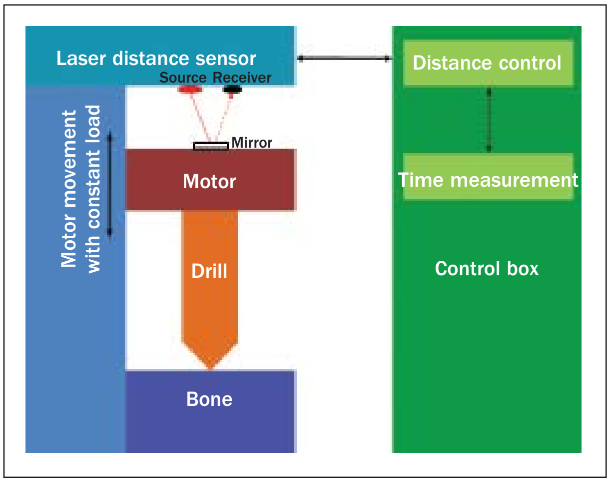


Fig 4 Schematic diagram of the customized and automated recording system of cutting efficiency. The constant load was imposed by the force that occurred when the drill motor executed a free fall. Drilling depth was acquired by measuring the displacement of the drill motor calculated by the traveling time of the laser, which was returned after being reflected in the mirror using a laser-distance sensor.

with irrigation using a 25°C coolant to simulate clinical settings (Fig 3).

Cutting Efficiency Measurement System

Cutting efficiency was defined as the drill volumetric removal rate calculated according to the following equation: $V = A \times dx/dt$. V represents the volume removed per unit time, A represents the cross-sectional area of the experimental osteotomy, and dx/dt represents the rate at which the drill advances into bone.[12] For this analysis, it was assumed that the diameter of the osteotomy equaled the diameter of the drill (ø 3.6 mm), with the depth of the osteotomy constantly maintained. With these assumptions, cutting efficiency is represented as follows: $V \approx A \times \Delta x/\Delta t = A \times D/T \propto 1/T$ (D = drill depth, T = drill time).

The system for measuring cutting efficiency is shown in Fig 4. Cutting efficiency was defined as the time necessary for a drill to reach a predetermined drilling depth under a constant load. The constant load during drilling was defined as the force that occurs when the motor component (weight 1 kg) executes a free fall. The drilling depth was attained by measuring the displacement of the motor component attached to the drill. To measure this displacement, a laser distance sensor, which consisted of a source and a receiver, was located above the motor component. A mirror was attached to the top platform of the motor component in order to help calculate the time for the laser beam to travel from the source and return to the receiver. The calculated time was converted into distance using the velocity of the laser. The drilling depth was determined by this distance, while the drilling time during the movement of the motor component was measured by the control box.

Operational Procedure

The operational procedure for temperature measurement was consistent with the authors' previous study.[11] Drill speed was maintained at 1,500 rpm with a load of 4 ± 1 N. Drilling was executed to a depth of 15 mm, with a drilling time of 2.0 ± 0.1 seconds; the same held for withdrawing. After drilling using a 3-mm-diameter drill, the three variations were tested. Each drill design was evaluated 20 times without exchange throughout the experiment.

A modified cutting-efficiency measurement system was introduced in this study. Drill speed was maintained at 1,500 rpm with a load of 10 N. Drilling was executed to a depth of 15 mm. Only drilling time was measured for evaluation. The remaining process was identical to temperature measurement.

Statistical Analysis

The sample size—20 subjects in each group—was determined by following power analysis. Effect sizes for the temperature change and cutting time were assumed at 1.63 and 0.45, respectively, and the minimum alpha and beta error levels were set at 0.05 and 0.2, respectively. The power for this

Table 1 Heat Generation Following Osteotomy Preparation Using Two-, Three-, and Four-Fluted Drills (mean ± SD; °C)

	Two-fluted	Three-fluted	Four-fluted	*P* value
Predrilling temperature	30.6 ± 0.5[a]	30.9 ± 0.5[ab]	31.0 ± 0.4[b]	.023
Postdrilling temperature	38.9 ± 0.7[a]	41.6 ± 0.9[b]	46.2 ± 1.0[c]	< .001
Temperature change	8.3 ± 0.8[a]	10.8 ± 0.9[b]	15.1 ± 0.9[c]	< .001

Different superscript letters indicate significant differences.

Table 2 Cutting Efficiency in Osteotomy Preparation Using Two-, Three-, and Four-Fluted Drills (mean ± SD)

	Two-fluted	Three-fluted	Four-fluted	*P* value
Cutting time (s)	2.6 ± 0.2[a]	2.5 ± 0.1[b]	2.5 ± 0.1[b]	.028

Different superscript letters indicate significant differences.

Table 3 Effect Sizes of Pairwise Comparison of Temperature Change and Cutting Time Among Two-, Three-, and Four-Fluted Drills

Compared drills	Temperature change		Cutting time	
	Z value	Effect size	*Z* value	Effect size
Two- and three-fluted	5.24	0.82	2.43	0.38
Two- and four-fluted	5.42	0.86	0.98	0.15
Three- and four-fluted	5.41	0.86	1.96	0.31

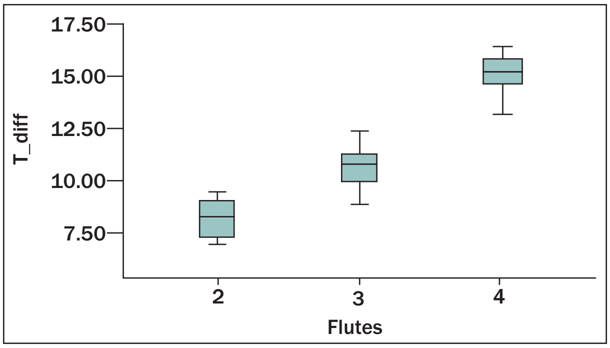


Fig 5 Heat generation following osteotomy preparation using two-, three-, and four-fluted drills.

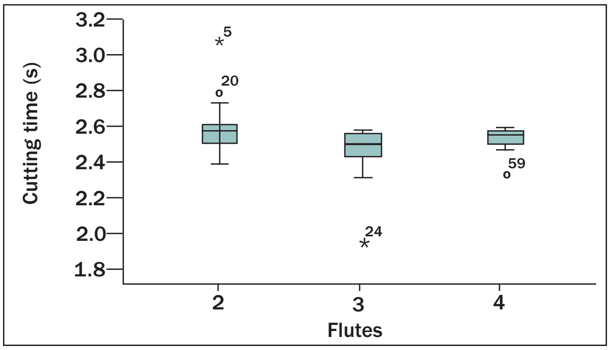


Fig 6 Cutting efficiency in osteotomy preparation using two-, three-, and four-fluted drills.

analysis with a sample size of 20 was obtained as 0.87 to find cutting time differences among three groups. The distribution of temperature measurements and cutting time (see Tables 1 and 2) were significantly different from normal distribution by the Shapiro-Wilk test ($P < .05$), and a nonparametric Kruskal-Wallis test was performed for a three-group mean comparison. Post-hoc pairwise comparison was performed using the Mann-Whitney test, with Bonferroni-adjusted alpha level. The effect sizes were calculated using the *Z* values from the Mann-Whitney test divided by the square root of the sample size (40 for two groups), as shown in Table 3. The statistically significant level was determined at $P < .05$. Box plots for three groups were displayed for detailed information on the distributions (Figs 5 and 6). Statistical analysis was performed using the SPSS 19.0 software (IBM SPSS).

RESULTS

Temperature Changes

Mean temperature changes following drilling are shown in Table 1 and Fig 5. Mean temperature change was 8.3°C, 10.8°C, and 15.1°C for the two-, three-, and four-fluted drills, respectively. One-way analysis of variance (ANOVA) revealed statistically significant differences among the three drill variations ($P < .001$); as the number of flutes increased, elevation in mean temperature was observed.

Cutting Efficiency

Mean cutting efficiency following drilling is shown in Table 2 and Fig 6. Mean drilling time amounted to 2.6 seconds for the two-fluted drills and 2.5 seconds for the three- and four-fluted drills. A tendency toward increased or decreased cutting efficiency depending on the number of the flutes was not observed. One-way

ANOVA revealed statistically significant differences among the three drill variations ($P = .015$).

Pairwise comparison of temperature change and cutting time effect sizes among the three drill types is shown in Table 3.

The post hoc analysis disclosed statistically significant differences between the two- and three-fluted drills ($P = .016$), suggesting the cutting efficiency of the three-fluted drill was superior to that of the two-fluted drill. Differences between the two- and four-fluted drills were minimal ($P = .470$), as were any differences between the three- and four-fluted drills ($P = .226$). In summary, cutting efficiency of the three drill variations in descending order was: three-, four-, and two-fluted drills, with statistically significant differences between the three- and two-fluted drills.

DISCUSSION

In a previous study, the present authors evaluated the effect of drill–bone contact area on heat generation. The results showed that increased drill–bone contact area led to an increase in frictional heat.[11] As part of the continuing quest for optimal drill designs, a need for research on the optimal number of flutes and the effects of flute design on drilling stability, cutting efficiency, and frictional heat has been identified. The present study evaluated the influence of the number of drill flutes on heat generation, and the results suggest that an increased number of flutes translates into increased heat generation. The cause for this may be the increase in drill–bone contact area, which may increase frictional heat induction.

As the number of flutes increased, the frontal contact area of the drill increased. The frontal contact area, including the cutting edge, measured 4.5 mm^2, 4.6 mm^2, and 5.5 mm^2 for the two-, three-, and four-fluted drills, respectively.

The cross-sectional area of the flute measured 2.9 mm^2, 1.9 mm^2, and 1.2 mm^2 for two-, three-, and four-fluted drills, respectively. This makes it seem that the flute size has more significance than their number in terms of effective bone-chip removal. Drills with more flutes also exhibited increased mean temperature changes and reduced heat dissipation capabilities. It can be speculated that the narrowed paths of the drills with more flutes caused bone chips to accumulate in the channels, eventually resulting in elevated frictional heat levels. Therefore, in order to avoid elevated heat levels, channels that serve as a path for removal of bone chips should be large enough to permit efficient removal of debris.

A modified approach to measuring cutting efficiency was used in this study. In implant dentistry, the cutting efficiency of a drill is described as its volumetric removal rate.[12] The rate of drill advancement was adopted as a measure for drilling efficiency. The rate of material removal was found to increase when greater force and surface speed was applied. During the testing process, the normal load applied and the rotational speed of the drill remained fixed, so the volumetric removal rate could be used to calculate the ease of material removal.

The volumetric removal rate was determined by using the cross-sectional area of the osteotomy and the rate at which the drill advanced into bone. Since the cross-sectional area and the depth of the osteotomy were constant, the cutting efficiency was established as a function of the drilling time. In endodontics, the time required for Gates Glidden drills to penetrate to a specific depth while a constant force was recorded.[13] The decrease in cutting efficiency was calculated by dividing the mean cutting time of the control drills by the difference between the control and the experimental groups. Although the purpose and use of the Gates Glidden drills were quite different from those of the implant drills, the cutting efficiency of the Gates Glidden drill was also dependent on the cutting time. In orthopedics, the characteristic feed-rates corresponding to the specified axial thrust force while drilling to a determined depth were used for in vitro testing of cutting efficiency.[10] In the present study, similar to the above studies, cutting efficiency was recorded under constant load and depth and calculated as the function of the drilling time. The difference with this study was that laser distance sensors were incorporated to increase accuracy and reduce other external factors, such as a positive stop,[13] a linear variable differential transducer,[12] or surgeon trial and error.[10]

The number of cutting edges did not seem to be a determining factor for cutting efficiency in this study. There were no statistically significant differences between two- and four-fluted drills, just as there were no differences in cutting efficiency between three- and four-fluted drills. Thus, it may be surmised that an increased number of cutting edges does not necessarily translate into improved cutting efficiency. However, the difference between the cutting efficiency of the three-fluted drill and the two-fluted drill was statistically significant. This may be because of the cutting efficiency gained by the inherent stability and self-centering nature of the tripod as an engineering structure. A previous study supports this finding: It revealed that three flutes and three cutting edges allow for greater stability whether the drill is entering a site from a dead stop or already moving at a suitable cutting speed.[9]

Within the limitations of study, the observations suggest that a two-fluted drill would be preferable for osteotomy preparation relative to heat generation, whereas a three-fluted drill showed somewhat favorable cutting efficiency.

ACKNOWLEDGMENTS

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