

Heat Generation During Implant Drilling: The Significance of Motor Speed

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Purpose: The purpose of this study was to measure the heat generated from 3 drilling speeds (1,225, 1,667, and 2,500 rpm) using the armamentarium of 4 implant systems.

Materials and Methods: The mean rise in temperature, the time of drilling, and the time needed for pig jaw bone to return to the baseline temperature were monitored using 4 thermocouple technology.

Results: The mean rise in temperature, the time of drilling, and the time needed for the specimens to return to the baseline temperature were lower at 2,500 rpm than at 1,667 or 1,225 rpm ($P \leq .05$), regardless of the system used. The rpm also directly correlated to the amount of time the bone remained at an elevated temperature.

Conclusion: From a heat generation standpoint, we conclude that preparing an implant site at 2500 rpm could decrease the risk of osseous damage, which may affect the initial healing of dental implants. This may decrease the devital zone adjacent to an implant after surgery and be most advantageous in immediate load application to dental implants.

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Dental implants have become an accepted treatment modality. According to recent studies, there are more than 24 implant systems in international dental markets, and more than 400,000 dental implants are placed annually in the United States.^{1,2} Previously, healing of the implant was considered "successful" when it became encapsulated with fibrous tissue, ie, fibro-osseous integration.³ However, the presence of this pseudoperiodontium was associated with micro-

bial and mechanical problems leading to implant failure.⁴ The extensive studies conducted in Sweden (University of Göteborg) and Switzerland (University of Bern) in the 1970s introduced the concept of osseointegration, in which bone has a direct contact with the surface of the implant with no intervening fibrous tissue.^{5,6} At the present, there is general agreement that osseointegration is the more stable situation and results in a high success rate for up to 15 years.⁷

There are many parameters that must be considered during implant placement for osseous integration to occur. It has been postulated that a cascade of interactions follows the manipulation of the osseous tissue during implant bed preparation that determines the progress of bone healing. The term "atraumatic" surgical preparation is considered essential, which includes several conditions, including avoidance of excess heat generation during the preparation of the osteotomy. The amount of bone contact to the implant after surgical placement and initial healing is variable and dependent on several factors, including the thermal injury to bone during implant osteotomy.^{8,9}

Heat is always generated during implant drilling. Past implant studies to evaluate this event have been conducted in vivo and in vitro. The in vivo studies have shown the harmful role of heat production in subsequent bone healing and identified the critical temperature that bone can withstand without necrosis.⁸⁻¹⁰ In vitro studies have found that the overall concept of heat generation is considered multifacto-

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rial in nature,¹¹ and most reports restrict their investigation to 1 or 2 factors.¹²⁻¹⁶

Previous reports have implied that slow-speed drilling during the implant site preparation will reduce heat generation because the frictional heat was assumed to be less compared with high-speed motors. For example, the study of Reingewirtz et al¹⁷ observed that 600 rpm reduced the heat production during bone cutting, and the author recommended reduced drill speeds in dense bone, to reduce heat generation. Almost all of the implant systems in the United States dental market recommend using a drill speed between 1,500 and 2,000 rpm, and many commercial motors do not rotate more than 1,650 rpm. The purpose of this study was to compare the heat generated with different drill speeds during implant site preparation, using 4 of the most commonly used implant systems.

Materials and Methods

The present study was conducted on porcine jaw bone following the clinical procedures commonly used in implant dentistry.^{7,18} The rationale for choosing pig jaws was the histologic and chemical similarity of pig bone with human bones.¹⁹

Nine fresh pig heads were obtained and prepared in a manner to separate the maxillae from the mandibles. The edentulous region between the canine and the first premolar was selected for drilling and was radiographed to observe the limiting structures and determine the osteotomy depths in the maxillary (Mx) and mandibular (Md) specimens. Then the specimens were kept frozen until used. Two hours before each study, the specimens were thawed in a thermostat-controlled bath filled with isotonic saline (0.9% of NaCl) adjusted at 37°C. Mucoperiosteal flap surgery was then performed to expose the bone in the region of interest, in a routine similar to that used for implant surgery. Temperature measurements were made during each site preparation with 4 type K Chromel-Alumel thermocouples (Omega Engineering, Stamford, CT). Each thermocouple was placed at 1 mm from the anticipated periphery of the hole, corresponding to each drill, at the buccal, mesial, distal, and lingual sites, respectively. The thermocouples were inserted into 0.15-mm-diameter holes prepared by a twist drill and an endodontic file No. 15. These thermocouples were inserted 8 mm below the surface and parallel to the prepared sites. Once the thermocouples were placed, the specimens were re-immersed in the warm saline bath for 10 minutes to re-establish the baseline temperature. Care was taken during the study to ensure each of the initial specimens was at 37°C before drilling. If the temperature

dropped under 37°C, the specimen was reimmersed in the warm saline bath.

The surgical sites were prepared to a constant 8-mm depth to avoid the mandibular canal, maxillary sinus, or opposing cortical plate and to eliminate the variable of drilling depth. Two contra-angled handpieces were used with different gear ratios mounted to a surgical motor (Steri-Oss surgical console; Nobel BioCare, Yorba Linda, CA) to control the different rpm values of the study. The surgical motor provides the operator with a specific combination of the gear ratio and the reduction percentage of the motor to obtain the 3 different speeds (ω) that were studied ($\omega_1 = 1,225$ rpm, $\omega_2 = 1,667$ rpm, and $\omega_3 = 2,500$ rpm).

The 2 wire leads of each thermocouple were connected to the appropriate channel of a thermocouple input nodule (Keithley Data Acquisition and Data Control, Cleveland, OH). This model system was interfaced to a personal computer (Multitech 900; Multitech Industrial Corp, Taiwan, Republic of China) using an Easyest LX data acquisition software program (Keithley Asyst Data Acquisition, Taunton, MA). The program was configured to simultaneously record input from all 4 thermocouples. The sampling rate was set at 1 measurement per second for each thermocouple, with a reported accuracy of 0.01°C. The software allowed plotting the time and the change in temperature (ΔT) in the x-y axes.

To ensure a constant clinical distance (1 mm) between the edge of the hole and the thermocouple for each osteotomy, the drill was first placed onto the bone to measure its diameter. Then the 4 holes were created 1 mm beyond the edge of the predicted surgically produced hole for the thermocouples to a depth of 8 mm. The thermocouples were then inserted before the drilling. The orifice of each thermocouple-containing hole was isolated by pink wax to prevent irrigation fluid from entering and reducing the bone temperature. These preoperative procedures were repeated for each consecutive drill evaluated, to allow recording of the intrabone temperature through a constant amount of intervening bone (1 mm³). That is, using the smallest-diameter drill, temperature measurements were made 1 mm from the drilling site at a depth of 8 mm from the surface (ie, at the extreme depth of the hole). Then the thermocouples were removed, the diameter of the next larger drill was measured on the bone, and new thermocouple channels were drilled 1 mm beyond the boundary of the new hole. This was repeated until the largest-diameter drill had been used.

Four implant drilling systems were evaluated in this study: Two internally irrigated systems (Steri-Oss [Nobel BioCare] and Paragon [Sulzberg, Germany]) and 2 externally irrigated systems (Branemark [Nobel Bio-

Table 1. SYSTEM EVALUATED, NUMBERS, AND DIAMETER OF DRILLS EXAMINED

| System | No. of Drills | Drill Diameter (mm) | | | | | |
|-------------|---------------|---------------------|-----|------|-----|-----|----|
| BioHorizons | 6 | 1.5 | 2 | 2.5 | 3 | 3.4 | 4 |
| Branemark | 4 | 2 | 3 | 3.85 | 4.3 | NA | NA |
| Steri-Oss | 4 | 2 | 2.7 | 3.35 | 3.8 | NA | NA |
| Paragon | 3 | 2.3 | 3.2 | 4.2 | NA | NA | NA |

NOTE. BioHorizons and Branemark are external irrigated systems; Steri-Oss and Paragon are internal irrigated systems.

Abbreviation: NA, not applicable.

Care] and the first generation of the Maestro system [BioHorizons, Birmingham, AL]). Between 3 and 6 different diameter drills were compared (Table 1).

All osteotomies were performed by the same operator (S.T.) following the manufacturer's operating manual and using room-temperature normal saline as coolant. The bone density was D2 in the mandible (Md) and D3 in the maxilla (Mx), using the tactile methods described by Misch.²⁰ The number of sites performed and the groups studied are illustrated in Table 2.

The mean rise in temperature (ΔT) was recorded for each drill in each system, at each site (Md or Mx), relative to the baseline temperature and the rotational speed used. This was accomplished by recording the baseline temperature ($^{\circ}\text{C}$) and the peak temperature ($^{\circ}\text{C}$) displayed for each of the 4 thermocouples. The mean and the standard deviation of these 4 values were calculated for each group. Data were stored in a personal computer and then statistically analyzed using the statistic software package SAS (SAS Institute, Cary, NC) for personal computers. Data were subjected to a 3-way analysis of variance (ANOVA) and the 2-paired Student Newman-Keuls tests. The α level was set a priori at .05.

Table 2. EXPERIMENTAL SITES, SPEEDS, AND SPECIMEN NUMBERS

| | Steri-Oss (Internal Irrigation) | Branemark (External Irrigation) |
|----------|------------------------------------|------------------------------------|
| Maxillae | | |
| | 1,225 rpm, n = 6 | 1,225 rpm, n = 6 |
| | 1,667 rpm, n = 6 | 1,667 rpm, n = 6 |
| | 2,500 rpm, n = 6 | 2,500 rpm, n = 6 |
| Mandible | | |
| | 1,225 rpm, n = 6 | 1,225 rpm, n = 6 |
| | 1,667 rpm, n = 6 | 1,667 rpm, n = 6 |
| | 2,500 rpm, n = 6 | 2,500 rpm, n = 6 |

NOTE. This design was repeated for the Paragon (internal irrigation) and BioHorizons (external irrigation). Four implant systems were evaluated at 6 sites for each of 3 speeds, for a total of 72 sites/mandibles and 72 sites/maxillae (144 drilled sites in 9 heads).

Results

TEMPERATURE RISE (ΔT)

Internal Irrigated Systems

In the Steri-Oss system, the mean rise in temperature (ΔT) in Md and Mx specimens with different speeds is presented in Figure 1. The mean temperature rise at Md sites (Fig 1A) was significantly lower for ω_3 (2,500 rpm) with drill diameters of 2 and 3.8 mm and was similar at all speeds for the 3.25-mm-diameter drill and slightly higher for the 2.7-mm-diameter drill at 2,500 rpm versus 1,667 rpm but similar to 1,225 rpm. The slowest rpm (1,225) produced the highest temperature in the first and last drill in the sequence and similar to the fastest rpm for the intermediate drills.

For Mx specimens (Fig 1B), the 2,500 rpm speed (ω_3) caused slightly less rise in temperature at all drill diameters, except for the 2.7-mm drill. However, no significant statistical difference could be noted among the 3 speeds, except for the 3.8-mm drill. The intermediate speed (1,667 rpm) produced the highest temperature for all diameter drills.

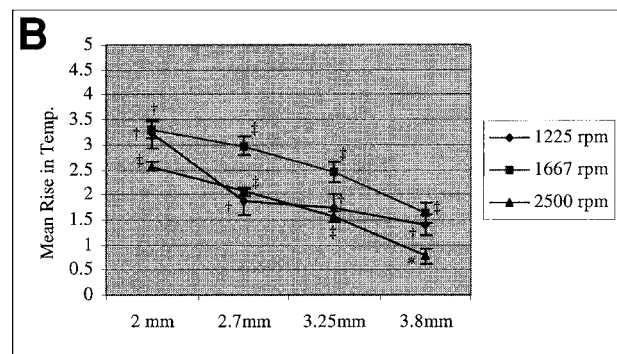
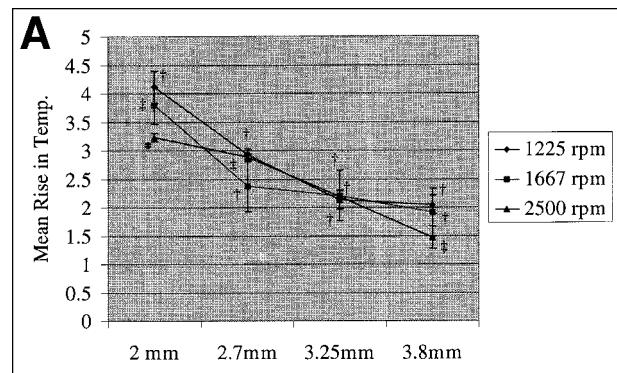


FIGURE 1. Graph representing the mean rise in bone temperature (ΔT) recorded using the Steri-Oss system in mandibular (A) and maxillary (B) specimens with different motor speed. Values are means, and bars represent SD. Values with different symbols (eg, †† vs †) are significantly different ($P \leq .05$), and difference applies to only the same drill diameter. No statistical comparison was performed between mandibular and maxillary.

For the Paragon system, for both Md and Mx sites, the ΔT was significantly lower ($P < .05$) at 2,500 rpm compared with the lower speeds regardless of the drill diameter used. The mean rise in temperatures ΔT recorded for Md and Mx is presented in Figure 2. The highest temperatures were recorded with all drills and sites (Mx and Md) with the slowest rpm (Fig 2).

External Irrigated Systems

For the Branemark system, the ΔT recorded exhibits significant difference between the variable speeds for the 4 drills evaluated in Md specimens (Fig 3A). In addition, similar to the vast majority of drills with the internal irrigation systems, ΔT was always lower at 2,500 rpm compared with that recorded with lower

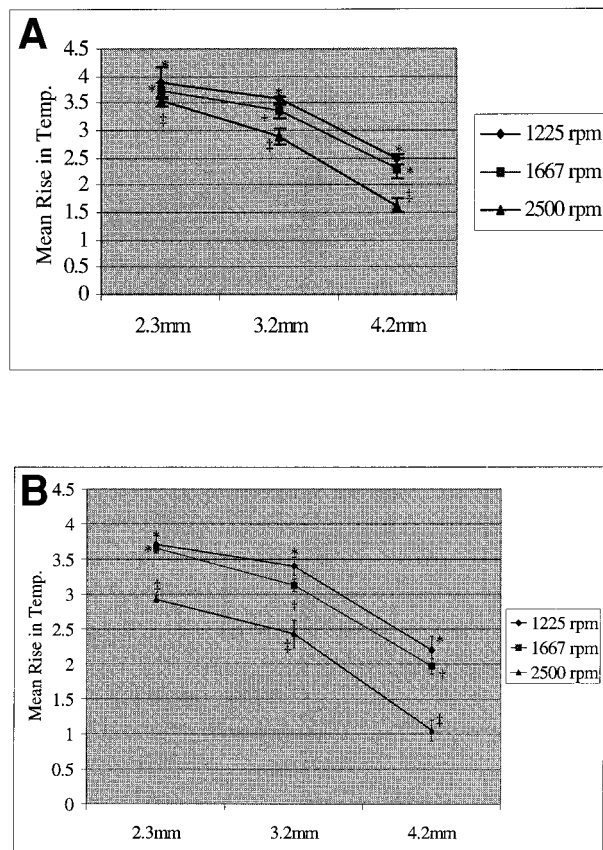


FIGURE 2. Graph representing the mean rise in temperature (ΔT) recorded using the Paragon system in mandibular (A) and maxillary (B) specimens with different motor speed. Values are means, and bars represent SD. Values with different symbols (eg, $\dagger\dagger$ vs \dagger) are significantly different ($P \leq .05$), and difference applies to only the same drill diameter. No statistical comparison was performed between mandibular and maxillary.

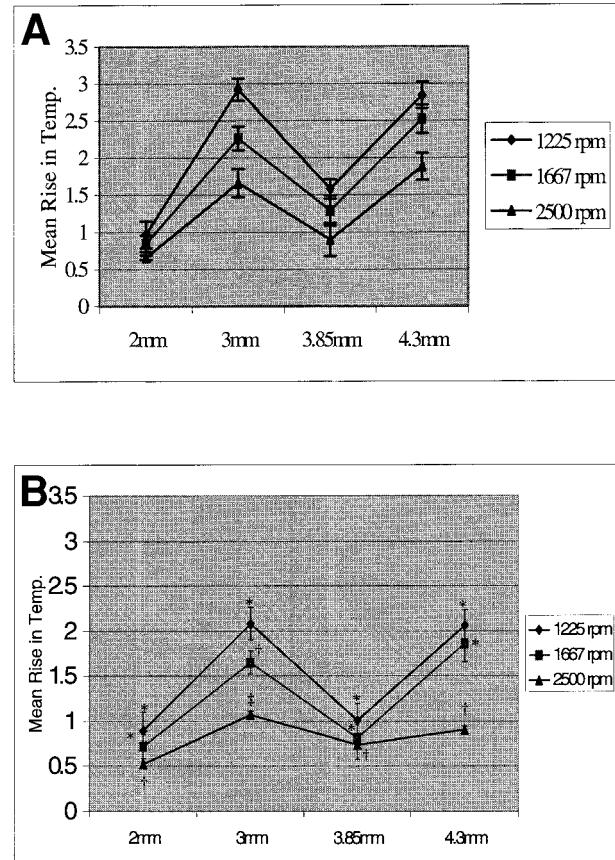


FIGURE 3. Graph representing the mean rise in temperature ΔT recorded using the Branemark system in mandibular (A) and maxillary (B) specimens with different motor speed. Values are means, and bars represent SD. Values with different symbols (eg, $\dagger\dagger$ vs \dagger) are significantly different ($P \leq .05$), and difference applies to only the same drill diameter. No statistical comparison was performed between mandibular and maxillary.

rpms. The highest temperatures were recorded with all drill diameters at the lowest rpm (1,225) (Fig 3A).

For Mx specimens, the high speed also generates less heat compared with the lower speed. The T assessed with different speeds for Md and Mx specimens are similar in that the highest bone temperature was recorded for the slowest speed and for the final drill used before implant insertion (4.3 mm) (Fig 3B).

For the first generations of BioHorizons system, 6 drills were evaluated. The ΔT recorded with different speeds and the statistical analysis performed are included in Figure 4. In Md specimens, the ΔT monitored showed significantly lower values using 2,500 rpm for 5 of the 6 drills evaluated. The slowest rpm (1,225) constantly showed the highest temperature changes (Fig 4A).

In Mx specimens, ΔT recorded with 2,500 rpm was lower than that recorded with 1,667 rpm for all the drills used. Again, the slowest rpm resulted in the highest temperature changes (Fig 4B).

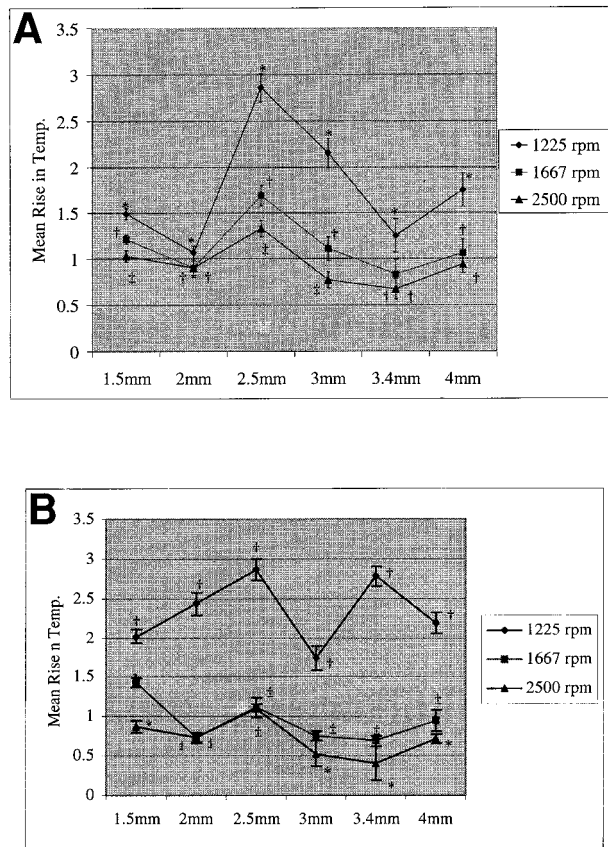


FIGURE 4. Graph representing the mean rise in temperature ΔT recorded using the BioHorizons system in mandibular (A) and maxillary (B) specimens with different motor speed. Values are means, and bars represent SD. Values with different symbols (eg, \ddagger vs \dagger) are significantly different ($P \leq .05$), and difference applies to only the same drill diameter. No statistical comparison was performed between mandibular and maxillary.

DRILLING TIME VERSUS THE TIME IT TAKES FOR BONE TO RETURN TO THE BASELINE TEMPERATURE

Internal Irrigation Systems

The results of the drilling time (t) and time required for the specimens to return to baseline temperature (TB) using the Steri-Oss system are presented in Figure 5, for Md and Mx specimens, respectively. There was positive correlation between t and TB in all the parameters studied; that is, the longer it takes to drill, the longer it takes for the temperature to return to TB. In addition, the ANOVA showed a significant difference between t with different ω values; that is, the higher speed, the shorter was the drill time. It is of note that TB varied with the speed ω , and this observation was true for all of the drills used, regardless of the drilling site, whether it was Md or Mx, ($P \leq .001$).

The graphs illustrating the t and TB for each drill sequence in the system (2, 2.7, 3.25, and 3.8 mm) show negative correlation with the diameter (d) of the drill; that is, the largest drill diameter led to the lowest value of t and TB.

The Paragon system behaved similar to the Steri-Oss system (Fig 6A). The statistical analysis showed significant difference between t and TB at variable speed ($P \leq .001$). The maxilla had less t and TB compared with the mandible for each drill in the sequence for both of the internally cooled systems tested.

External Irrigation Systems

For the Branemark system, positive correlation between t and TB was also observed (Fig 7). In addition, as in all systems tested, the higher the speed ω , the shorter was the t ($P \leq .001$).

In contrast to the internal irrigation systems, no correlation could be found among the t, TB, and that of d. The lowest values of t and TB were obtained with the first drill (2 mm), whereas the highest values were detected with the second drill (3 mm). The third (3.85 mm) and the fourth (4.3 mm) drills exhibited lesser values than the second, but a higher value than the first. All values differ significantly from each other ($P \leq .005$).

For the BioHorizons system, the results of t and TB are illustrated in Figure 8. Positive correlation was found between t and TB with all of the drills used. Also, comparable results could be noticed between t and TB relative to the speed. The higher the speed, the lower were the t and TB.

Similar to the Branemark system, no correlation existed among t, TB, and d, albeit a lesser value than that of Branemark system was observed. The lowest value of t/d and TB/d was assigned to the fifth drill (3.4 mm), while the highest recorded was that for the first drill (1.5 mm).

Discussion

Previous studies have shown that osteonecrosis after bone drilling is a function of the rpm (degree and time).^{8,9,17} In this study, 3 speeds were evaluated and the time of drilling (t) or time required for the bone to return to baseline temperature (TB) was monitored. Results of this investigation clearly show that the higher the speed, the less was the heat generated. These findings were true regardless of the site of drilling, whether Md or Mx, or the implant system used. This is not to imply that rpm is the only factor. For example, the higher the rpm, the faster the drill reached the 8-mm depth of cutting. Thus, drilling time (t) was inversely related to the rotational speed of the drill. Slower rotational speeds required more drilling time, which produced more frictional heat.

No attempt was made during this study to assess the pressure (load) applied on the drill. Past studies indicate that varying amounts of pressure on the drill can modify the temperatures and the length of time to

FIGURE 5. Graphic presentation of the data showing the influence of the speed and both drilling time (t) and time to return to baseline (TB) using Steri-Oss system in mandibular (A and B) and maxillary (C and D) specimens. Values are means, and bars represent SD.

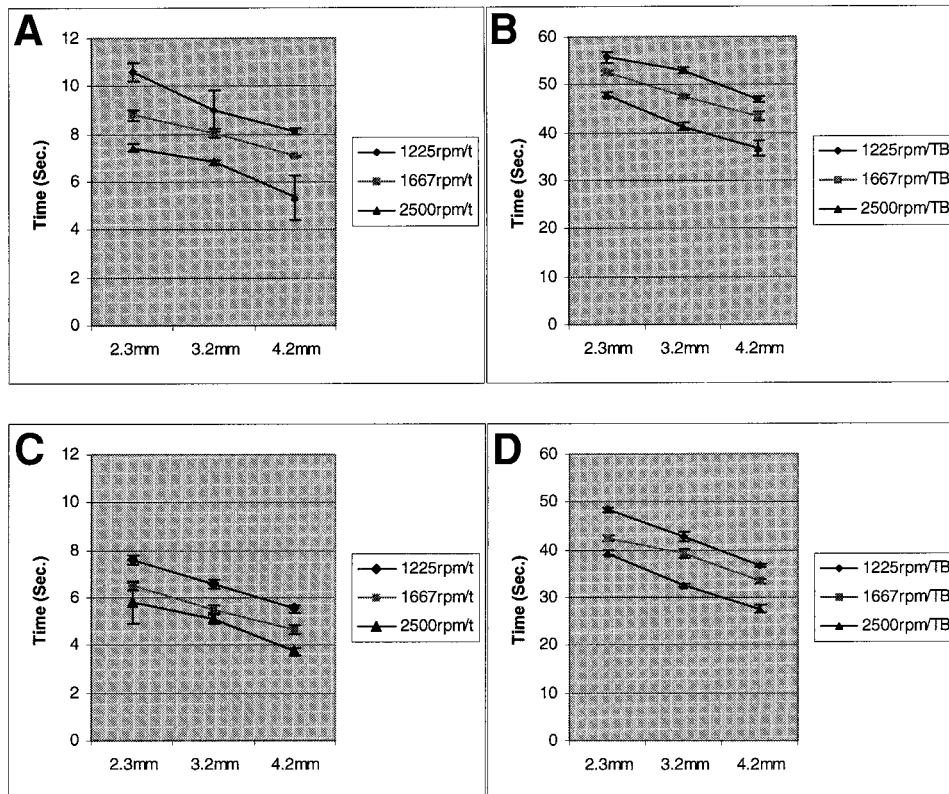
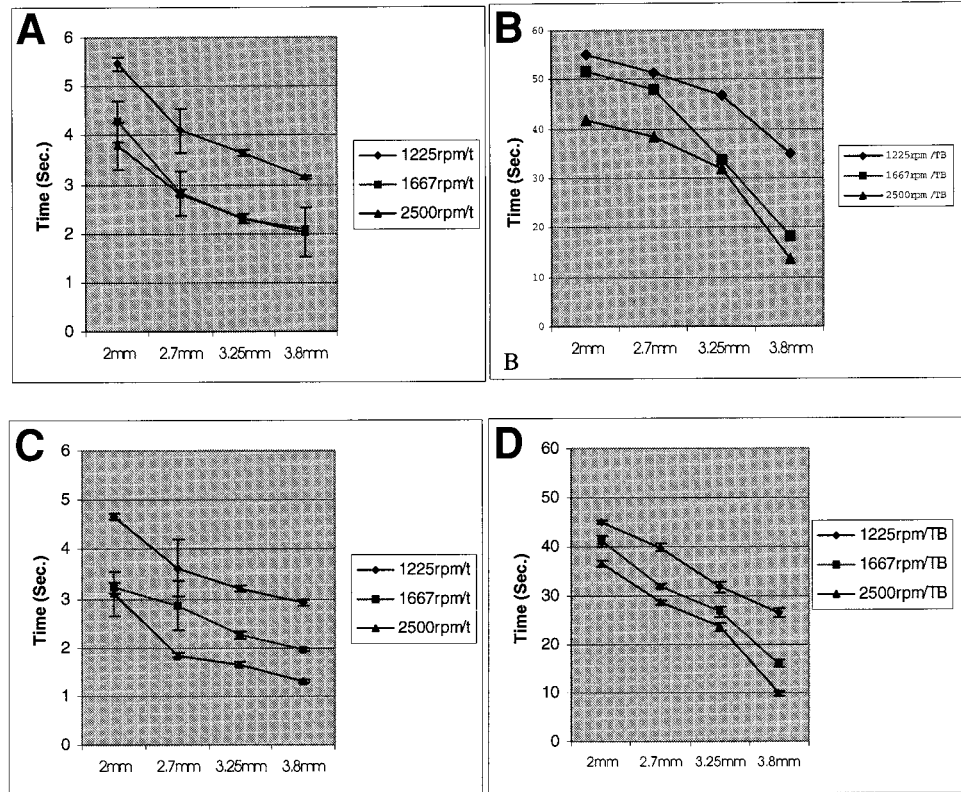


FIGURE 6. Graphic presentation of the data showing the influence of the speed and both drilling time (t) and time to return to baseline temperature (TB) using Paragon system in mandibular (A and B) and maxillary (C and D) specimens. Values are means, and bars represent SD.

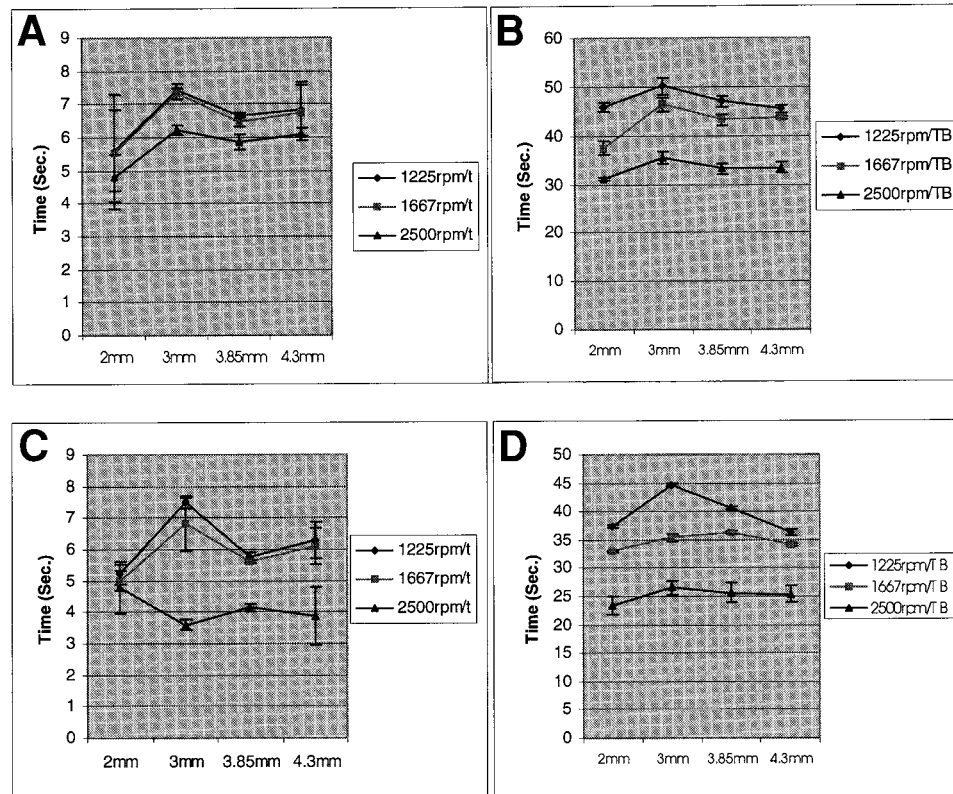
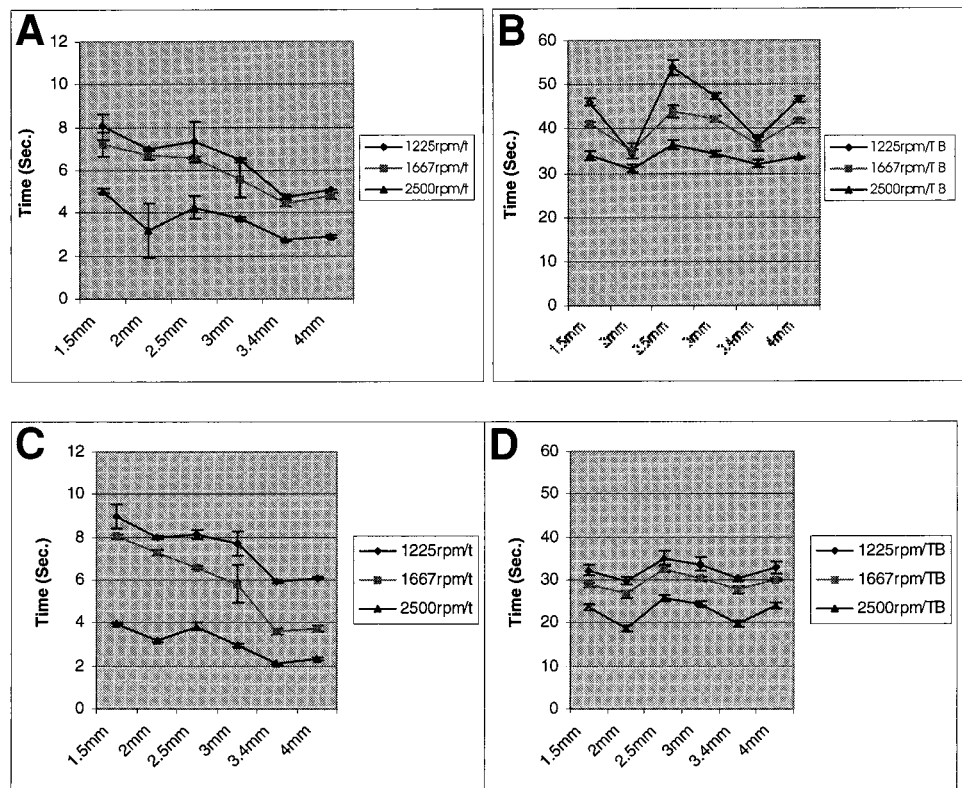


FIGURE 7. Graphic presentation of the data showing the influence of the speed and both drilling time (t) and time to return to baseline temperature (TB) using Branemark system in mandibular (A and B) and maxillary (C and D) specimens. Values are means, and bars represent SD.

FIGURE 8. Graphic presentation of the data demonstrating the influence of the speed and both drilling time (t) and time to return to baseline temperature (TB) using BioHorizons system in mandibular (A and B) and maxillary (C and D) specimens. Values are means, and bars represent SD.



prepare the bone site. Brisman²¹ compared the drilling at 1,200 rpm and 2,400 rpm under loads of 1.2 kg and 2.4 kg in dry bovine femoral bone. Less heat was generated with 2,400 rpm under 2.4 kg of force. Cordioli and Majzoub¹⁶ found that a drilling force of 2 kg falls in the range of values used under clinical condition.

The first drill of the Branemark externally cooled system tested in our study generated less heat than the final drill, while the first drill of externally cooled BioHorizons drill generated more heat than the final drill. On the contrary, the internal cooled systems had the most heat generated from the first drill. However, the differences are less than 1.4°C elevation above the body temperature. This report differs from that of, Lavelle and Wedgewood,¹² which reported that internal cooling prepares bone at a lower temperature. It should be emphasized that this report was not designed to evaluate internal versus external cooling. To accomplish this, the same design drill should be used. This study used differently designed drills manufactured by different companies. Hence, the lower temperatures for the 2 external cooled systems is interesting but, because the drill designs were all different, no comparison may be made between the general concepts of external versus internal cooling for a drill preparation.

Earlier studies⁸⁻¹² delineated the critical bone temperature beyond which bone necrosis may occur. However, the range of the safe drill speeds that a clinician could use was not clearly identified. All of the implant systems evaluated in this study provided an implant site, without exceeding the critical 4°C rise in bone temperature, and are acceptable for proper healing processes to proceed and create a direct bone-to-implant contact. However, there is a higher implant failure rate in the most dense bone types.²² Therefore, in some clinical situations, subtle differences in procedures such as the speed of drilling may alter the expected outcome. In all of these systems, the higher the rpm, the lower was the temperature rise. Thus, it is suggested that higher drill speeds be considered in clinical use, especially in more dense bone types.

Contrary to this report, Reingewirtz et al¹⁷ observed a positive correlation between the temperature rise and the rotation speed in an internal cooled system with rotations ranging from 0 to 10,000 rpm. However, their findings were based on 1 thermocouple inserted in dry ox femoral bone, 0.8 mm from the drilling site. The drilling was performed using a 2.3-mm round steel bur. The studies of Eriksson et al^{23,24} were designed to monitor the effect of heat on bone, which was assessed histologically, microradiographically, and through vital observation, without regard to the drilling sequences. Their observations

were also based on 1 thermocouple, which may be insufficient in monitoring the overall temperature rise of bone surrounding the implant site. In the present investigation, 4 thermocouples were inserted 1 mm from the drilling site, and the mean of the 4 readings was calculated for each drill. Thus, the overall thermal profile could be detected from different regions surrounding the site of drilling.

A positive correlation could be found between drilling time (t) and the time required to return to the TB, regardless of the drilling site or the implant system used. Thus, the more drilling time, the higher was the bone temperature and the more time was needed for the specimens to return to TB. More time was always needed to prepare the bone site at a drilling speed of 1,225 rpm than with either 1,667 or 2,500 rpm. The ANOVA always detected significant difference between drilling time and speed of rotation. This observation is in accordance with earlier reports. Reingewirtz et al¹⁷ also found that the temperature change was a function of the time of drilling and the motor speed rather than the drilling time alone. In addition, they observed that with greater rpm, less time was required to complete the drilling. For example, the drilling time recorded at 1,600 rpm was 6.24 seconds, while it was 3.69 seconds at 3,200 rpm.¹⁷ In another experiment, Brisman²¹ observed a reduction ranging from 30% to 40% in drilling time when drilling speed increases from 1,800 rpm to 2,400 rpm at 2,400 g of force. He also noticed that the drill geometry could significantly influence the results. Those observations were comparable to our results. For the Steri-Oss system, doubling the rpm results in 30% reduction in drilling time t and a 25% reduction in the TB in Md specimens, while in Mx specimens, the same drill diameter produced a 45% reduction in drilling time and a 19% reduction in TB. Similar findings could be seen in all of the other systems.

Interesting, although a similar relationship exists between change in bone temperature (ΔT) and both drilling time (t) and TB, this was true only within each system, rather than as an overall observation that can be applied to all implant systems (Table 3).

From Table 3, we can conclude that to drill 8 mm in depth using the 2-mm-diameter drill of the Bio-

Table 3. EXAMPLES OF CORRELATION OF DRILLING TIME (t) AND BASELINE TEMPERATURE (TB) RELATIVE TO ΔT WITHIN THE SYSTEM AT 2 DRILL DIAMETERS

| System | Diameter (mm) | ΔT | t | TB |
|-------------|---------------|-------------|-------------|-------------|
| Biohorizons | 2 | 0.9 (0.1) | 6.98 (0.08) | 34.4 (2.3) |
| Branemark | 2 | 0.97 (0.18) | 5.6 (0.27) | 45.8 (1.92) |
| Biohorizons | 3 | 1.11 (0.13) | 6.46 (0.27) | 47.2 (1.48) |
| Branemark | 3 | 2.92 (0.18) | 7.44 (0.37) | 50.2 (3.89) |

Horizons system, the time required for drilling will be 6.98 ± 0.08 second and the rise in temperature was $0.9 \pm 0.1^\circ\text{C}$, which needed 34.4 ± 2.3 seconds to return back to the TB of 37°C . The 2-mm drill of the Branemark system, using the same motor speed, displayed different values (both *t* and TB were statistically significantly different, $P \leq .05$). Thus, it seems that the drill design is also an important factor that influences both *t* and TB. As a result of these studies, the BioHorizons system has modified its drill designs to make them more efficient and able to prepare bone in less time. Further studies are in progress to reevaluate these modified conditions. Both systems used the same flow rate of external irrigation solution.

It is also significant to mention that, within the limit of this study, our results indicate that whether the irrigating saline was delivered internally or externally, the rise in temperature at any of the motor speeds used would not cause necrosis to the bone. The greatest temperature recorded was 41.5°C for less than 20 seconds in the D2 bone of the mandible. In the Eriksson and Adell²⁴ study on rabbit bone, a temperature of 40°C held for 7 minutes or 47°C for 1 minute was found to cause bone necrosis. However, in theory, if the clinician changes the drills and begins drilling in the osteotomy before allowing the temperature returning to baseline, the 40°C increases for each drill may indeed gradually rise to a clinical concern. If approximately 30 to 60 seconds is required to return to the TB, beginning the next size drill in the osteotomy before allowing the bone to return to baseline return may eventually heat the bone more than 10°C (47°C when baseline is body temperature). Hence, although independent drill performance may only increase bone temperatures 0.5° to 4°C , the use of 2 to 5 additional reentries into the osteotomy by the sequential drilling may further elevate bone temperatures. In addition, it is suggested the clinicians interrupt the drilling procedure at least every 5 seconds for at least 10 seconds, while saline is applied to the bone. The interruption will dramatically decrease the time the bone temperature is elevated. This is most important in the most dense bone types.

Clinically, a higher failure rate of dental implant in D1 bone has been reported and attributed to (among other things) the heat generation resulting from the friction of the drill with the dense cortical bone.²¹ However, in almost all of the long-term follow-up studies, the rotation speed used falls within the range of 1,500 to 2,000 rpm. The results of the present study using wet pig jaws suggest that it may be advantageous to use higher speed (2,500 rpm) in dense bone, because it will reduce the time of drilling and it will generate less heat that will return back to normal temperature in a shorter time. Further *in vivo* studies are needed to support this conclusion.

Immediate loading of dental implants has been increasingly performed during the past 10 years. In theory, a smaller devitalized zone next to an immediate loaded implant would be beneficial. Because elevations in bone temperature above 41°C are able to increase the devitalized zone after initial surgery, the concepts presented here may have most benefit in implants that are loaded before bone remodeling is completed. The amount of time to return to a TB suggests a waiting period should exist between each drill sequence in an osteotomy.

Within the limits of the present study, we can conclude that the bone drilling at 2,500 rpm generates less heat than at slower speeds. Published clinical trails by BioHorizons Dental Implants have used a drill speed of 2,500 rpm during a 3-year period and have reported survival above 99% implant integration in all bone densities.²⁵ Further investigation is needed to evaluate the performance of other dental implants in humans using this drill speed.

The purpose of this *in vitro* study was to evaluate the effect of drill speed on the temperature of adjacent bone using 4 commercial implant drilling systems. Two of these systems were externally irrigated, whereas the other 2 were internally irrigated during the drilling procedure. The increase in bone temperature, the time required to prepare an 8-mm osteotomy, and the time required for the bone to return to a TB were measured. In all systems, a drill speed of 2,500 rpm resulted in less heat, less time to prepare the osteotomy, and less time for the bone to return to the original TB. The manufacturers of the systems evaluated suggest drilling speeds between 1,650 (Steri-Oss, Paragon) and 2000 (Branemark) rpm. These speeds have led to very high success rates of osteointegration. However, in the most dense bone types, higher drill speeds may prove to be beneficial because of the reduced heat generation. Reducing the heat generated during implant insertion may indeed decrease the devitalized zone next to an implant after surgical placement.

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References

1. Watson MT: Implant dentistry: A 10 year retrospective report. *Dent Prod Rep* December:26, 1996
2. Watson MT: Specialists' role in implant dentistry rooted in history: A survey of periodontist and maxillofacial surgeons. *Dent Prod Rep* January:14, 1997
3. Weiss CM: Tissue integration of dental endosseous implants: Description and comparative analysis of the fibro-osseous integration and osseous integration systems. *J Oral Implantol* 12: 169, 1986

4. Alberktsson T, Sennerby L: Direct bone anchorage of oral implants: Clinical and experimental considerations of the concept of osseointegration. *Int J Prosthet* 3:30, 1990
5. Branemark P-I: Osseointegration and its experimental background. *J Prosthet Dent* 50:399, 1983
6. Schroeder A, Van Der Zypen E, Stich H, et al: The reaction of bone, connective tissue and epithelium to endosteal implants with sprayed titanium surfaces. *J Maxillofac Surg* 9:15, 1981
7. Adell R, Lekholm U, Rockler R, et al: A 15 year old study of osseointegrated implant in the treatment of the edentulous jaw. *Int J Oral Surg* 10:387, 1981
8. Eriksson A, Alberktsson T, Grane B, et al: Thermal injury to bone: A vital microscopic description of heat effects. *Int J Oral Surg* 1:115, 1982
9. Eriksson RA, Alberktsson T: Temperature threshold levels for heat-induced bone tissue injury: A vital microscopic study in rabbit. *J Prosthet Dent* 50:101, 1983
10. Eriksson RA, Alberktsson T: The effect of heat on bone regeneration: An experimental study in rabbit using the bone growth chamber. *J Oral Maxillofac Surg* 42:705, 1984
11. Tehemar SH: Factors affecting heat generation during implant drilling: A review of biological observations and future considerations. *Int J Oral Maxillofac Implantol* (in press)
12. Lavelle C, Wedgewood D: Effect of internal irrigation on frictional heat generated from bone drilling. *J Oral Surg* 38:499, 1980
13. Matthews LS, Hirsch C: Temperatures measured in human cortical bone when drilling. *J Bone Joint Surg Am* 54:297, 1972
14. Rafel SS: Temperature changes during high-speed drilling on bone. *J Oral Surg Anesth Hosp Dent Serv* 20:475, 1962
15. Yacker M, Klein M: The effect of irrigation on osteotomy: depth and bur diameter. *Int J Oral Maxillofac Implantol* 11:634, 1996
16. Cordioli G, Majzoub Z: Heat generation during implant site preparation: An in vitro study. *Int J Oral Maxillofac Implantol* 12:186, 1997
17. Reingewirtz Y, Szmukler-Moncler S, Senger B: Influence of different parameters on bone heating and drilling in implantology. *Clin Oral Implant Res* 8:189, 1997
18. Misch CE: Root form surgery in edentulous mandible: Stage I implant insertion, *in* Misch CE (ed): *Contemporary Implant Dentistry*. St Louis, MO, Mosby, 1999, pp 347-371
19. Buser D, Nydegger T, Hirt HP, et al: Removal torque values of titanium implants in the maxilla of miniature pigs. *Int J Oral Maxillofac Implant* 13:611, 1998
20. Misch CE: Density of bone: Effect on treatment plans, surgical approach, healing and progressive bone loading. *Int J Oral Implant* 6:23, 1990
21. Brisman DL: The effect of speed, pressure and time on bone temperature during drilling of implant sites. *Int J Oral Maxillofac Implantol* 11:35, 1996
22. Truhlar RS, Morris HF, Ochi S, et al: Second stage failures related to bone quality inpatients receiving endosseous dental implants: DICRG Interim report #7. *Implant Dent* 3:252, 1994
23. Eriksson RA, Alberktsson T, Magnusson B: Assessment of bone viability after heat trauma: A histological, histochemical and vital microscopic study in the rabbit. *Scand J Plast Reconstr Surg* 18:261, 1984
24. Eriksson RA, Adell R: Temperatures during drilling for the placement of implants using the osseointegration technique. *J Oral Maxillofac Surg* 44:4, 1986
25. Misch CE, Hoar J, Hazen R, et al: Bone quality based implant system (BioHorizons® Maestro™ Dental Implants): A prospective study of the first two years of prosthetic loading. *Oral Implantol* 1999