

Original

Effect of pre-drilling on intraosseous temperature during self-drilling mini-implant placement in a porcine mandible model

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Abstract: This *in vitro* study investigated intraosseous heat production during insertion, with and without pre-drilling, of a self-drilling orthodontic mini-implant. To measure temperature changes and drilling times in pig ribs, a special testing apparatus was used to examine new and worn pre-drills at different speeds. Temperatures were measured during mini-implant placement with and without pre-drilling. The average intraosseous temperature increase during manual mini-implant insertion was similar with and without pre-drilling ($11.8 \pm 2.1^\circ\text{C}$ vs. $11.3 \pm 2.4^\circ\text{C}$, respectively; $P = 0.707$). During pre-drilling the mean temperature increase for new drills was 2.1°C at 100 rpm, 2.3°C at 200 rpm, and 7.6°C at 1,200 rpm. Temperature increases were significantly higher for worn drills at the same speeds (2.98°C , 3.0°C , and 12.3°C , respectively), while bone temperatures at 100 and 200 rpm were similar for new and worn drills ($P = 0.345$ and 0.736 , respectively). Baseline bone temperature was approximated within 30 s after drilling in most specimens. Drilling time at 100 rpm was 2.1 ± 0.9 s, but was significantly shorter at 200 rpm (1.1 ± 0.2 s) and 1,200 rpm (0.1 ± 0.03 s). Pre-

drilling did not decrease intraosseous temperatures. In patients for whom pre-drilling is indicated, speeds of 100 or 200 rpm are recommended, at least 30 s after pilot drilling.

Keywords: orthodontic screw; mini-implant; self-drilling; pre-drilling; heat production.

Introduction

Anchorage control is a basic requirement for successful orthodontics. Dental anchorage is defined as resistance to unwanted tooth movement, while absolute anchorage is defined as the absence of anchorage unit movement from reaction forces applied to move teeth (1). To achieve absolute anchorage, mini-implants, dental implants, mini-plates, or palatal implants are usually used. Although the survival rate for traditional dental implants is around 94 to 100% (2), they are very rarely applied for orthodontic reasons because of the difficulty of removing osseointegrated implants from bone after completing tooth movement. In addition, the cost of such implants is high. In 1997 Kanomi introduced mini-implants that were specially developed for orthodontic applications (3).

Because of their many advantages (noncompliance independent, low morbidity, and good patient acceptance), mini-implants are the most widely used absolute anchorage device (4). Despite their small diameter and short length, mini-implants provide stable anchorage for various types of tooth movement, including intrusion,

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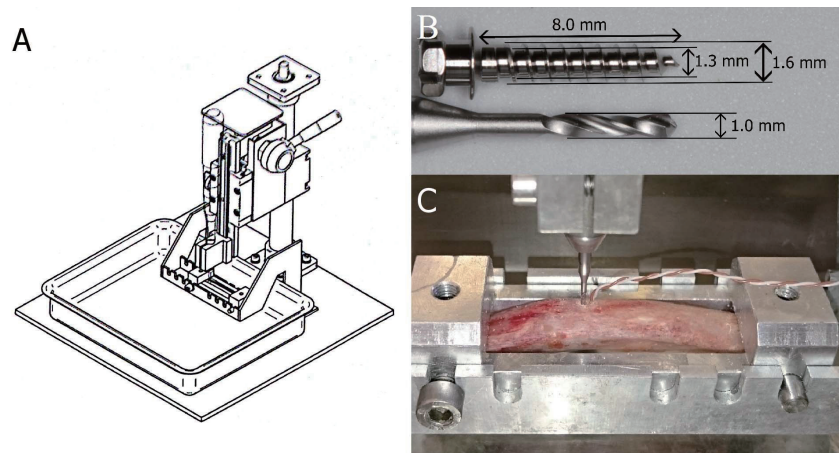


Fig. 1 A: Illustration of apparatus used in conjunction with a physio-dispenser and surgical handpiece, to maintain constant drilling parameters. B: Parameters of the investigated mini-implant and pilot drill in this study. C: Method for pre-drilling and temperature measurement with a thermocouple probe.

retraction, and protraction (5). There are two principal insertion methods: self-drilling, which does not require the drilling of a pilot hole, and non-self-drilling (i.e. self-tapping), which requires a pilot hole before implant placement. Clinical use of mini-implant anchorage may result in neighboring tooth injury, implant fracture, and implant loosening (6). Mini-implant stability was found to be influenced by cortical bone thickness, implant diameter, inflammation of peri-implant tissues, and a high mandibular plane angle (7). Furthermore, torque and heat during insertion of mini-implants may be associated with early implant loss (8-10). Tachibana et al. calculated the optimal pilot hole diameter to ensure optimal insertion torque for self-drilling mini-implants (10), while Matsuoka et al. investigated the heat produced during placement of self-drilling mini-implants without pilot hole preparation (9).

Bone is a poor thermal conductor; thus, any heat generated within it may remain localized, possibly resulting in increased local temperatures and necrosis (11). Previous studies reported a lower mandibular mini-implant success rate (8,12-15), perhaps due to microcracks caused by over-torqueing in harder and thicker bone (10) and possible overheating. The mandible has a thicker cortex and denser bone, which ensure excellent primary stability. However, these same characteristics may increase the risk of overheating during drilling procedures, although the exact temperature and corresponding interval for thermal osteonecrosis have not been determined (16-18). Osteonecrosis occurs when temperatures increase to 47°C (13,19). Pre-drilling of orthodontic mini-implants was shown to optimize insertion torque and avoid bone histological damage (10). In addition, the pilot hole diameter/mini-implant diameter ratio, i.e. optimal pre-drilling,

improves implant stability (7); however, pre-drilling can have effects on intraosseous temperatures during mini-implant placement. To our knowledge, intraosseous heat (temperatures measured in bone, under the cortex) during mini-implant placement and the thermal effects of pre-drilling on self-drilling mini-implant placement have not been previously investigated. Furthermore, although the effects of using worn drills on temperature increase have been studied, the evidence regarding worn orthodontic pilot drills is limited.

We investigated change in bone temperature during pre-drilling for a self-drilling orthodontic mini-implant. In addition, we calculated the optimal drilling speed (i.e., the speed associated with the lowest temperature increase) for pilot hole preparation. Finally, the thermal effects of worn pilot drills were assessed in this *in vitro* study.

Materials and Methods

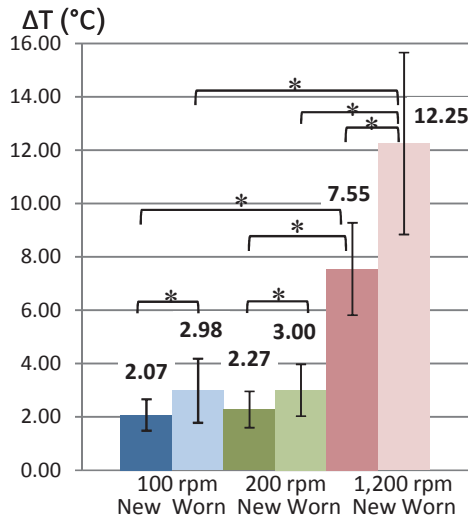
In this *in vitro* study, bone specimens (length, 50 mm) prepared from pig ribs were used to simulate human mandibles. Ribs with a cortical thickness of 2.1-2.2 mm were selected from the same animal. The pigs used in this study had been sacrificed for reasons unrelated to the present study, and bone specimens were stored in a deep freezer until the present analysis. Before the experiment, bone specimens were warmed to room temperature in a physiologic saline tank, which avoided further exsiccation.

To ensure consistent drilling parameters, such as pressure, perpendicular drilling direction, and drilling depth, mini-implant predrills were tested with a special testing apparatus (Fig. 1A), as described in our recent study (20). The apparatus was able to register the exact drilling time

Table 1 Intraosseous temperature increase during pilot hole preparation

Drill type	Speed (rpm)	Mean ΔT	Temperature changes		
			SD	Min	Max
New	100	2.07	0.59	1.0	3.8
	200	2.27	0.68	1.1	4.3
	1,200	7.55	1.73	4.0	11.2
Worn	100	2.98	1.2	1.0	6.2
	200	3.0	0.97	1.6	6.3
	1,200	12.25	3.41	7.4	25.1

SD: standard deviation.

**Fig. 2** Mean intraosseous temperature increase during pre-drilling with new and worn drills at various drilling speeds. *Significant differences in means ($P < 0.05$).

and interface with a physio-dispenser unit (Implantmed SI-923; W&H, Bürmos, Austria) and a surgical hand-piece (SL-11; W&H).

Temperature was measured with Cu/CuNi thermocouple sensors (diameter, 0.5 mm; TC Direct, Budapest, Hungary) connected to a digital thermometer and data registration tool (EL-EnviroPad-TC, Lascar Electronics Ltd., Salisbury, UK), at a resolution of 0.1/1°C and 1 measurement per second. Sensors were placed at a depth of 5 mm in the bone and 1 mm from bone cavities, for use as a metal drilling guide. The cavities for the sensors were prepared with a 0.5-mm-diameter stainless steel twist drill (203RF, Hager & Meisinger GmbH, Düsseldorf, Germany).

This study utilized the 1.0-mm-diameter drills (112-MC-201) and 1.6 × 8 mm orthodontic mini-implants of the Jeil Dual-Top Anchor System (JA, JEIL Medical Corp., Seoul, Korea) (Fig. 1B, C). To simulate worn pre-drills, 150 drillings were performed in pig ribs, with the same number of sterilization cycles in a regular autoclave (SterilClave 24 BHD, Cominox Co., Carate Brianza, Italy), before testing. Six drills (3 new and 3 worn) were

used to drill a total of 240 holes in pig ribs. Each was used to drill 40 holes at a speed of 100, 200, or 1,200 rpm. During the experiment, drills were identified by the previously milled strip markings on the shank area. Each drill could be correctly identified by examining the number of strips (from 1 to 6). At lower drilling speeds (100 and 200 rpm) an axial load of 20 N was applied; at 1,200 rpm, a reduced, 5-N load, was used, in accordance with previous recommendations (21).

In 10 randomly chosen cases, after cavities had been drilled with pilot drills a hand drive was used to immediately place mini-implants (similar to clinical conditions) while continuously registering intraosseous temperatures. In 10 other cases mini-implants were placed into intact bone without pilot hole preparation, and temperature registration was performed as described above.

Statistical analysis

After data collection, statistical analyses were performed with SPSS v 20.0 (SPSS, Chicago, IL, USA). The Kolmogorov-Smirnov test was used to test the normality of the data distribution for each group. The values for heat and preparation time at different drilling speeds for new and worn drills were analyzed by the nonparametric Kruskal-Wallis and Wilcoxon signed-rank tests. Differences in heat production by mini-implant insertions with and without pilot holes were assessed with the Student *t*-test. *P* values less than 0.05 were considered to indicate statistical significance.

Results

Intraosseous thermal changes during mini-implant pre-drilling are shown in Table 1 and Fig. 2.

Intraosseous heat production for new and worn drills was significantly associated with drilling speed ($P < 0.001$ for both, Kruskal-Wallis test). In a comparison of new and worn drills at the same drilling speed, heat production was similar at 100 and 200 rpm ($P = 0.345$ and $P = 0.736$, respectively; Wilcoxon signed-rank test). However, there was a significant difference in the heat produced between drilling speeds of 100 rpm and 1,200

Table 2 Drills and drill speeds used in the study

Drill types and speeds (rpm)		Difference of means (°C)	P value*
New 100	vs. New 200	0.20	0.345
New 100	New 1,200	5.48	<0.001
New 200	New 1,200	5.28	<0.001
Worn 100	Worn 200	0.02	0.736
Worn 100	Worn 1,200	9.27	<0.001
Worn 200	Worn 1,200	9.25	<0.001
New 100	Worn 100	0.91	0.002
New 200	Worn 200	0.73	0.021
New 1,200	Worn 1,200	4.70	<0.001

*Wilcoxon signed-rank test.

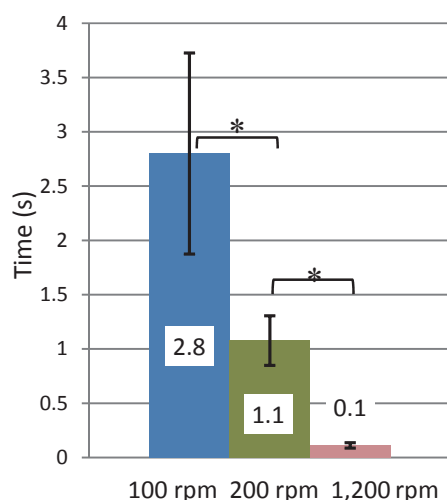


Fig. 3 Preparation times required for standard bone cavity drilling by new pilot drills at various drilling speeds. *Significant differences in means ($P < 0.05$).

rpm and between speeds of 200 rpm and 1,200 rpm ($P < 0.001$ for both comparisons, Wilcoxon signed-rank test); that is, the higher drilling speed was associated with higher temperatures. The heat produced was significantly higher for worn drills than for new drills at 100 rpm ($P = 0.002$), 200 rpm ($P = 0.021$), and 1,200 rpm ($P < 0.001$) (Wilcoxon signed-rank test). These results are summarized in Table 2. After drilling the cavities, bone temperatures began to decrease and had usually returned to baseline temperatures after approximately 30 s.

Differences in the drilling times required for standard bone cavity preparation were significant between speeds of 100 and 200 rpm and speeds of 200 and 1,200 rpm ($P < 0.001$ for both comparisons, Wilcoxon signed-rank test) (Fig. 3).

When a pilot hole was pre-drilled, the average heat produced by insertion of mini-implants with hand winding was $11.8 \pm 2.1^\circ\text{C}$. Without pilot hole preparation, mini-implant insertion resulted in a similar increase in intraosseous heat, namely $11.3 \pm 2.4^\circ\text{C}$ ($P = 0.707$,

t -test). Figure 4 shows a randomly selected temperature measurement. After pre-drilling the bone with a worn drill at 1,200 rpm, a mini-implant was placed and hand-driven with a screwdriver. In this simulated clinical environment, the temperature curve of the bone was in the so-called “danger zone” ($>47^\circ\text{C}$) for a cumulative duration of approximately 27 s. Scanning electron microscopy micrographs of new and worn drills are shown in Fig. 5.

Discussion

The overall failure rate for mini-implants varies considerably. A review by Papageorgiou et al. reported a rate of 0.0 to 40.8% (mean, 14%), and the overall failure rate for mandibular miniscrew implants was 1.56 times that of maxillary implants (22). Several factors were associated with miniscrew failure, including cortical bone thickness, bone density, screw diameter, screw length, screw taper, shape of the screw thread, insertion method (self-drilling vs. self-tapping), insertion torque, insertion angle, treatment period, amount of loading, direction of loading, microfracture of alveolar bone, and overheating (6,13,22).

Heat-induced trauma to bony tissue causes changes in local vasculature, osseous maintenance, fat cells, and cellular protein function. A temperature increase to 40°C initiates vascular hyperemia; however, continued thermal elevation to 53°C halts blood flow entirely (19,23). One study reported that the threshold for thermal damage to osseous tissue was between 44°C and 47°C (23); however, another study found that a temperature increase of only 4.3°C resulted in significant differences in the quality of bone newly formed around an implant (24).

Matsuoka et al. investigated bone temperatures during self-drilling mini-implant placement and found that in a mandible model (cortical thickness, approximately 2 mm) mean temperature change was between 5.0°C (at 50 rpm) and 11.1°C (at 250 rpm) (9). In contrast, hand-wound screw placement resulted in significantly higher

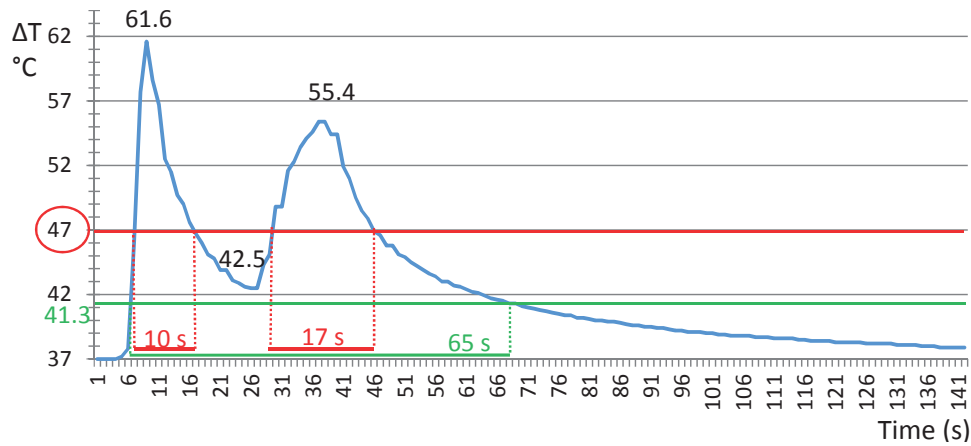


Fig. 4 Graph of representative temperature measurements. The first temperature peak was observed during use of a worn drill at 1,200 rpm for pre-drilling of the pilot hole in bone. The temperature decreased but did not reach baseline. During insertion of the orthodontic mini-implant, temperature increased again and reached a second peak. Interestingly, the temperature did not return to baseline during the 140-s observation period. The red (47°C) and green (41.3°C) lines represent two widely accepted threshold temperatures, while the values under the curve indicate durations of exposure to temperatures in the “danger zone”.

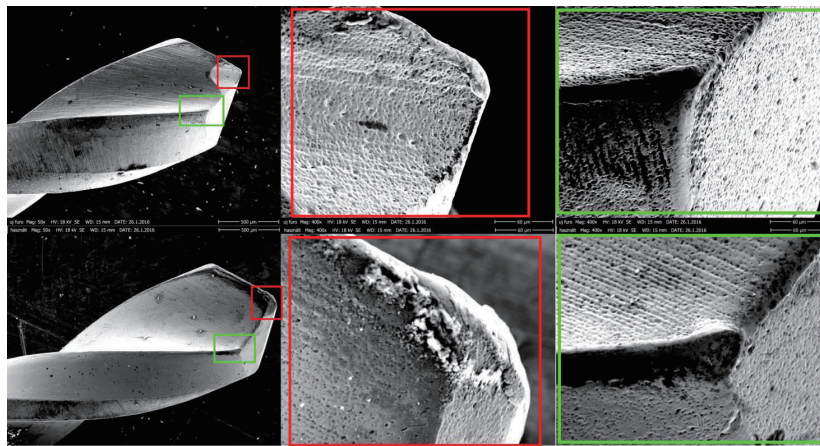


Fig. 5 Scanning electron microscopy micrographs show new and worn drills. The apex of the worn drill is rounded, which increases the point angle (red rectangles), while cutting edges are visibly blunter after 150 uses (green rectangles). Accurate clinical assessment of 1-mm drills is likely to be very difficult in the absence of magnification.

temperature increases in our study ($11.8 \pm 2.1^\circ\text{C}$ for pilot hole preparation; $11.3 \pm 2.4^\circ\text{C}$ without pre-drilling), as compared with the previously reported temperature of 5°C at 50 rpm. However, methods for measuring temperature differed between studies. In the present study, thermocouple sensors were placed at a depth of 5 mm in bone. In contrast, Matsuoka et al. used a contact sensor glued on the surface of the cortex (9). Variability between studies might also be attributable in part to the difference in mini-implant products assessed (JEIL Medical Corp. vs. Bident Co., Ltd., Tokyo, Japan).

The need for pre-drilling before mini-implant placement has been discussed in earlier studies (25-27). A review recommended use of a 1-mm-diameter pilot hole

for a 1.6-mm-diameter mini-implant when cortical bone thickness was greater than 1.5 mm but less than 2.5 mm, as in the present study (25). In contrast, another study found that, for a stable mini-implant, the optimal pilot hole should be 69 to 77% of the diameter of the mini-implant. As compared with the “no pre-drilling” method, only a 1.3-mm pilot hole was able to reduce insertion torque values in the mandible model of a 1.6-mm-diameter mini-implant (7). Our results indicate that a 0.625 (1 mm / 1.6 mm) pilot hole ratio for the mini-implant pre-drilling method did not reduce intraosseous heat in comparison with self-drilling. Moreover, pilot hole preparation exposes bone to additional thermal stress (Fig. 4). Combined pre-drilling and mini-implant insertion

resulted in a 27-s interval in the “danger zone” ($>47^{\circ}\text{C}$) and approximately 1 min at a temperature greater than 41.3°C .

To our knowledge, only one previous study investigated the thermal effects of mini-implant pilot hole preparation in an *in vitro* mandible cortical model. Nam et al. investigated combinations of 600 and 1,200 rpm speeds and 10-N and 5-N axial loads on heat production during the drilling of a 5-mm-deep cavity (21). Interestingly, general temperature elevation was much greater than in the present study. The authors recommended the use of new drills at 600 rpm with a 10-N load ($\Delta T = 15.8^{\circ}\text{C}$) or at 1,200 rpm with a 5-N load ($\Delta T = 11.4^{\circ}\text{C}$). Our recommendation, namely, to use a speed of 100 or 200 rpm during pre-drilling, assumes a temperature elevation of approximately 2°C (Table 1, Fig. 2). At 1,200 rpm, our new drills generated much less heat, as compared with the findings of Nam et al.; however, worn drills resulted in similar temperature elevations (12.3°C in the present study vs. 11.4°C in the previous study). These discrepancies between past and present results are likely partially attributable to the different methods used for temperature registration (thermocouple sensors vs. infrared thermography) and the different models used (pig rib vs. bovine rib; both with a cortical thickness of about 2 mm). However, in the present study a much higher axial load was applied during low speed drilling (20 N vs. 10 N). One reason for the higher axial load was that the drill was not able to prepare the cortex at a load of 5 N and a speed of 600 rpm (21). Augustin et al. found that while an independent increase in axial load or drilling speed caused a temperature increase, simultaneous increases in both resulted in more effective cutting and no significant increase in temperature (16). In contrast, the combination of high axial loading and low speed was sufficiently effective and caused only mild temperature increases in our study. The present findings are consistent with those of a previous study, which found that a combination of lower drilling speed and higher pressure was necessary for better bone regeneration. A drilling speed of 230 rpm and a pressure of 20 N was optimal in that *in vivo* study (28). Furthermore, Reingewirtz et al. concluded that an increase in pressure (8N, 13 N, 20 N) at drill speeds of 400 and 800 rpm modestly increased temperature but significantly decreased drilling time (29).

It is important to mention that, as was the case in the study of Nam et al. (21), irrigation was not used in the present *in vitro* study, and past and present results are thus comparable. With respect to the potential temperature increase, irrigation may have only limited benefits when drilling is performed at low speeds; however, irrigation

seems to be necessary when a worn drill is used for high-speed drilling (1,200 rpm). In contrast, a previous study used saline flushing of the bone surface during pre-drilling (10), while another study found that continuous irrigation with saline solution was necessary to prevent necrosis during pre-drilling (12). Jeong et al. found that bone temperatures were similar during external cooling, even when a flapless implant procedure and surgical drill guides were used (30). However, another study reported that low-speed drilling (<1500 rpm) without irrigation did not cause overheating during drilling (31). Although higher speeds resulted in significantly faster drilling in the present study, every drilling time (2.8, 1.1, and 0.1 s at 100, 200, and 1,200 rpm) yielded clinically acceptable results in our opinion (Fig. 3).

In conclusion, pre-drilling of 1.6-mm self-drilling mini-implants with a 1-mm diameter pilot drill did not decrease intraosseous temperatures when the mini-implant was placed into a mandible bone model (cortical thickness, 2.1-2.2 mm). Future studies should examine the effects of different pilot hole sizes on temperature and investigate the results and possible benefits *in vivo*. With respect to intraosseous heat, the preferred technique is pre-drilling—with a 1-mm-diameter drill—at a speed of 100 or 200 rpm and an axial load of 20 N. Use of pilot drills at 1,200 rpm is not recommended, especially when the drills are worn (used ≥ 150 times).

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Conflict of interest

None declared. None of the authors have any commercial associations or financial disclosures. All the authors have read the paper in its present form and approved its content.

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