J Periodontal Implant Sci. 2023 Feb;53(1):85-95
https://doi.org/10.5051/jpis.2201400070
pISSN 2093-2278·eISSN 2093-2286

JPIS Journal of Periodontal & Implant Science

Research Article
Implant Science

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Effects of a simplified drilling protocol at 50 rpm on heat generation under water-free conditions: an *in vitro* study

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Received: Mar 8, 2022
Revised: Apr 22, 2022
Accepted: Jun 2, 2022
Published online: Jun 20, 2022

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Funding
This study was supported by the National Research Foundation of Korea (NRF; Daejeon, Republic of Korea) funded by the

ABSTRACT

Purpose: In recent years, guided implant surgery has been widely used for the convenience of patients and surgeons. Further streamlining the surgical procedure would make implant surgery more convenient. Low-speed water-free conditions are often used in guided implant surgery. Therefore, in this study, we attempted to confirm once again whether drilling was safe at a low speed without water. The main purpose of this study was to evaluate whether a simplified drilling protocol that omits some intermediate steps in the drilling process was safe from the viewpoint of heat generation.
Methods: D1 density artificial bone blocks were drilled under 50 rpm, 10 N·cm water-free conditions, and the surface temperature was measured using a digital infrared camera. First, drilling was performed with the sequential drilling method, which is the most widely used technique. Second, for each drill diameter, the temperature change was measured while performing simplified drilling with omission of the previous 1, 2, or 3 steps.
Results: In sequential drilling, the heat generated during drilling at all diameters was less than the critical temperature of osteonecrosis (47°C) except for the ⌀2 drill. Statistical significance was observed in all groups when comparing sequential and simplified drilling in the ⌀3.2, ⌀3.8, and ⌀4.3 drills ($P<0.001$). However, in the simplified drilling procedures, the temperature was below the osteonecrosis threshold temperature (47°C) except for the ⌀4.3 drill with the omission of the previous 3 steps (⌀3.0, ⌀3.2, and ⌀3.8).
Conclusions: In general, drilling under low-speed, water-free conditions has shown stable results in terms of heat generation. Simplified drilling showed statistically significantly greater heat generation than sequential drilling. However, most of the diameters and omitted steps seem to be clinically acceptable, so it will be useful if an appropriate selection is made according to the patient's clinical condition.

Keywords: Dental implants; Osseointegration; Osteonecrosis; Osteotomy

INTRODUCTION

Dental implants have become a popular dental treatment modality due to their high success rate and shortened treatment period. Long-term studies have shown that implants are highly

Korea government (MSIT) (grant No. NRF-2021R1G1A1004716).

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Author Contributions

Conceptualization: Hyun-Joo Kim; Formal analysis: Hyeon-Ji Jang, Jin-Un Yoon, Ji-Young Joo, Ju-Youn Lee, Hyun-Joo Kim; Investigation: Hyeon-Ji Jang, Jin-Un Yoo, Hyun-Joo Kim; Methodology: Hyeon-Ji Jang, Jin-Un Yoon, Hyun-Joo Kim; Project administration: Hyun-Joo Kim; Writing - original draft: Hyeon-Ji Jang, Jin-Un Yoon, Hyun-Joo Kim, Ji-Young Joo; Writing - review & editing: Ju-Youn Lee, Hyun-Joo Kim.

predictable treatments and are continually evolving through the accumulation of treatment experience, the development of materials, and the modification of protocols [1]. Successful implant treatment requires considering the patient's pain and comfort throughout the treatment process [2]. The surgeon's ease of operation is another factor to consider for the completeness of the procedure. In order to satisfy both the patient and the dentist in relation to implant surgery, various methods that can simplify the process and shorten the treatment have been introduced, including immediate implant placement into the extraction site [3], immediately loaded implant-supported prostheses [4], and flapless implant surgery [5]. In recent years, computer-assisted guided surgery without a flap has been widely used to improve the convenience and satisfaction of the dentist and patient [6,7]. However, treatment modalities are changeable only to the extent that they do not inhibit osseointegration.

A non-traumatic surgical procedure is essential for successful primary healing of the implant and subsequent stable osseointegration [8]. According to a review, excessive heat generated during drilling can cause changes in the turnover activity of the bone due to changes in hyperemesis, osteonecrosis, fibrosis, and osteoclast activity [9]. According to a series of studies by Eriksson and Albrektsson [10-12], the critical temperature threshold, which causes irreversible damage to the bone, is 47°C exceeding 1 minute. Many factors can influence the temperature of drilling [9], such as drill-related factors (e.g., drill diameter, length, sharpness, and design) [13,14], water-related factors (e.g., the presence of water-cooling, methods of water-cooling, and the temperature of the water) [15], implant site-related factors (e.g., bone density, cortical bone thickness, and bone volume) [16], and factors related to the surgical procedure (e.g., drilling speed, torque, drilling protocol, and template design.) [17-19].

Traditionally, the implant placement process takes place under water-cooling at high speeds above 1,000 rpm. It is known that high-speed drilling with water-cooling has the least impact on bone tissue [20]. However, in recent years, due to several advantages, low-speed drilling without water-cooling has been proposed as an alternative to conventional drilling [18,21,22]. In low-speed drilling, it is easier to modify the path if necessary, allowing the operator to perform more accurate drilling. In addition, low-speed drilling is possible without water because it does not generate as much heat as high-speed drilling [21]. Therefore, difficulty in securing visibility due to the presence of water and patient discomfort can be solved. Other advantages include the ability to obtain a bone chip without saliva contact during drilling, which is useful for bone grafting requiring a small amount of bone graft material [23]. At present, this concept has been introduced into various guided implant surgery protocols by the manufacturers.

The traditional and most widely used drilling method is to sequentially form the implant site while increasing the drilling diameter. Eriksson and Adell [24] reported that sequential drilling techniques were less invasive in an *in vivo* study. They concluded that the sequential drilling process did not cause overheating because the amount of bone that could be removed at one time was limited. A single drilling technique has been proposed as an alternative to sequential drilling to reduce the hassle of the drilling process. Bulloch et al. [25] investigated whether a wire-guided single-drilling protocol generated more heat when compared to traditional sequential drilling. According to them, the cannulated single-drill technique did not induce more bone heating than conventional sequential drilling with or without a surgical guide. In a recent study, Jimbo et al. [26] proposed a simplified drilling protocol (using a pilot drill and a final drill) that skipped the intermediate steps in drilling, and reported no differences in osseointegration compared to traditional sequential drilling through animal experiments.

Drilling several steps during implant site preparation is a cumbersome process for doctors and patients. Therefore, it would be highly advantageous if the drilling process in implant surgery could be simplified by performing low-speed osteotomy without irrigation. Until now, no studies have evaluated the stability of the simplified drilling protocol under low-speed drilling without irrigation. This study compared the traditional sequential drilling protocol and the simplified drilling protocol (partial omission of intermediate-stage drilling) in terms of heat generation in low-speed drilling without irrigation.

MATERIALS AND METHODS

Bone model

In this *in vitro* study, an artificial bone block (Sawbones, Vashon Island, WA, USA) was used to observe the thermal changes during implant drilling. D1 density artificial bone blocks were used to create the most heat-prone conditions during drilling. The D1 artificial block bone was based on the American Society for Testing and Materials. The block bone consisted of an outer cortical layer (thickness, 3 mm; density, 0.8 g/mL) and an inner cancellous layer (thickness, 15 mm; density, 0.48 g/mL).

Experimental set-up

The drilling procedures were performed using a special computer-aided customized surgical system (DIO Drilling and Torque Tester; M.I. Tech, Busan, Korea). With this equipment, accurate drilling can be reproduced repeatedly under specific settings for rotations per minute (rpm) and torque. A surgical drilling unit (DIO, Busan, Korea) was used, and the drilling speed and torque were set at 50 rpm and 10 N·cm, as recommended by the manufacturer for guided implant surgery (DIO Navi, DIO) (**Figure 1A**). No water cooling was performed during the drilling process, and the drill holes were irrigated using 37°C saline solution after each drilling step to minimize the heat generated by previous drilling.

The experimental model was set up as shown in **Figure 1B**. Temperature changes during drilling were measured directly by thermal imaging using a digital infrared camera (AVIO

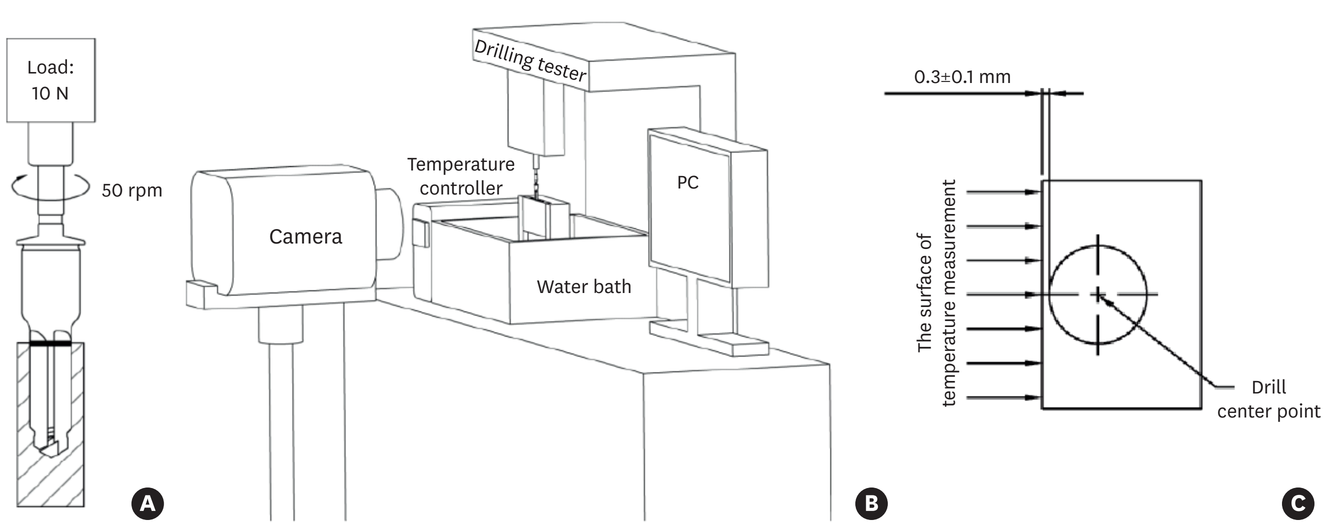

Figure 1. Experimental design. (A) Schematic diagram of the experimental set-up. (B) The drilling speed and torque were set at 50 rpm and 10 N·cm, respectively. (C) The thickness left between the final drill hole and the outer surface of the artificial bone block was planned to be 0.3±0.1mm.

https://doi.org/10.5051/jpis.2201400070

S300SR; Nippon Avionics Co., Tokyo, Japan). The temperature measurement range of the camera is −40°C to 500°C, and thermal decomposition is possible to 0.03°C at 30°C. The thermal measurement accuracy of the camera is ±1°C. The camera was placed 0.20 m away from the artificial bone block for maximum spatial resolution. Temperature changes per 0.05–0.1 second were recorded.

The bone block was placed in a specially designed thermostatic bath (Teahwa Tech., Busan, Korea) to maintain a constant temperature during the experiment. The constant temperature bath was equipped with a temperature controller (MISUMI Co., Seoul, Korea), which confirmed that the temperature remained constant. The artificial bone was immersed in about 20 mm, corresponding to half of the depth of the water tank. The temperature of the constant temperature bath was maintained at 36.5°C±1°C so that the temperature of the artificial bone block could be maintained above 31.5°C±1°C. The temperature of the laboratory was maintained at 36.5°C±1°C.

Experimental protocol

The prepared artificial bone block was inserted into a specially designed vise device and immobilized during the experiment. The drilling was repeated 30 times per drill diameter under the setting of the experimental apparatus described above to record the temperature change. In order to minimize the heat generation effect according to the drill length, the length of the drill used was limited to 8.5 mm. In order to record the heat generation most accurately, the thickness left between the final drill hole and the outer surface of the artificial bone block was planned to be 0.3±0.1 mm. For this purpose, the position of the initial drilling was calculated and set for each drill diameter (**Figure 1C**).

The experiment was divided into 2 groups: the sequential drilling group, in which all drilling processes were sequentially performed from initial drilling to final drilling, and the simplified drilling group, which partially omitted several steps before final drilling. The sequential drilling and simplified drilling groups were set as follows (**Table 1**).

- Sequential drilling (mm): Drilling step by step in the following order:
  ⌀2.0→ ⌀2.7→ ⌀3.0→ ⌀3.2→ ⌀3.8→ ⌀4.3

- Simpl.ified drilling (mm): Drilling by omitting 1 or more previous steps for each drill diameter:
  ⌀3.2: ⌀2.7→ ⌀3.2
  ⌀3.8: ⌀2.7→ ⌀3.0→ ⌀3.8, ⌀2.7→ ⌀3.8
  ⌀4.3: ⌀2.7→ ⌀3.0→ ⌀3.2→ ⌀4.3, ⌀2.7→ ⌀3.0→ ⌀4.3, ⌀2.7→ ⌀4.3

In the sequential drilling group, the temperature was measured in each step while drilling from ⌀2.0 to ⌀4.3, and in the simplified drilling group, the temperature was measured during the final drilling step after drilling in the order described above. The temperature changes during the course of the experiment were recorded using a real-time thermal image analysis program on a computer connected to the thermal imaging camera. Next, the temperature was recorded by selecting the single point that showed the highest temperature in the drilling process by 1 experimenter. All experimental procedures were repeated 30 times.

https://doi.org/10.5051/jpis.2201400070

Table 1. Drilling protocol: sequential versus simlified drillng

Final drill diameter (mm)	ø2.7	ø3.0	ø3.2	ø3.8	ø4.3
ø3.2					
Sequential	•	•	•		
Simplified	•		•		
ø3.8					
Sequential	•	•	•	•	
Simplified	•	•		•	
	•			•	
ø4.3					
Sequential	•	•	•	•	•
Simplified	•	•	•		•
	•	•			•
	•				•

Statistical analysis

The data were analyzed using SPSS version 23.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to calculate the mean and standard deviation of the temperature for each drill diameter. The Kolmogorov and Shapiro-Wilk normality tests showed that the temperature according to the drill diameter did not satisfy the assumption of normality. A nonparametric test (the Mann-Whitney *U* test) was performed to compare the sequential drilling protocol and the simplified drilling protocol. *P* values less than 0.05 were regarded as statistically significant.

RESULTS

The mean and standard deviation of the temperature distribution according to the drill diameter and drilling protocol are shown in **Table 2**. Representative thermal infrared camera measurement images according to the drill diameter and drilling protocol are presented in **Figure 2**.

Sequential drilling under low-speed without irrigation

Comparing the 6 drill diameters of the sequential drilling process, the highest mean temperature was observed at ⌀2.0 (55.78°C ± 0.81°C). Conversely, at ⌀4.3, the average temperature was the lowest (38.70°C ± 0.38°C). When the average drilling temperature was compared between the ⌀2.0, ⌀2.7, ⌀3.0, and ⌀4.3 drills, it was observed that as the drill diameter increased, the

Table 2. Temperature distribution according to the drill diameter and drilling protocol

Drilling protocol	Final diameter (mm)	Mean±SD (°C)
Sequential drilling	ø2.0	55.78±0.81
	ø2.7	43.73±0.41
	ø3.0	39.98±0.33
	ø3.2	40.41±0.53
	ø3.8	40.24±0.31
	ø4.3	38.70±0.38
Simplified drilling	ø3.2 (ø2.7→ø3.2)	44.77±0.81
	ø3.8 (ø2.7→ø3.0→ø3.8)	45.15±0.62
	ø3.8 (ø2.7→ø3.8)	46.33±1.03
	ø4.3 (ø2.7→ø3.0→ø3.2→ø4.3)	41.36±0.50
	ø4.3 (ø2.7→ø3.0→ø4.3)	44.70±0.26
	ø4.3 (ø2.7→ø4.3)	50.57±0.71

Data were presented as mean and SD. All drilling protocols were repeated 30 times.
SD: standard deviation.

 https://doi.org/10.5051/jpis.2201400070

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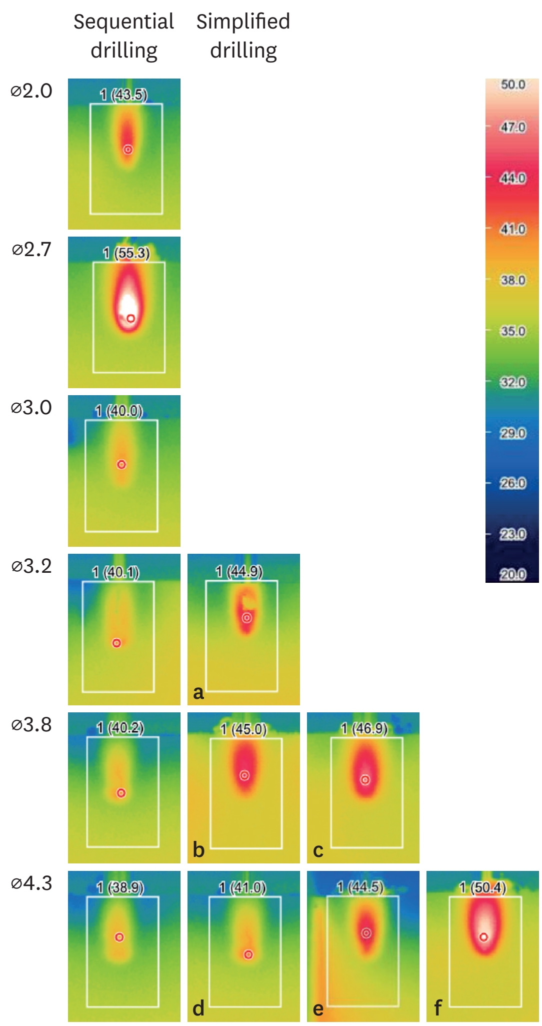

Figure 2. Representative image of temperature distribution according to drill diameter and drilling protocol. Among the images recorded by the thermal imaging camera, the single point showing the highest temperature during the drilling process was designated.
a: ⌀2.7→⌀3.2, b: ⌀2.7→⌀3.0→⌀3.8, c: ⌀2.7→⌀3.8, d: ⌀2.7→⌀3.0→ ⌀3.2→⌀4.3, e: ⌀2.7→⌀3.0→⌀4.3, f: ⌀2.7→⌀4.3.

temperature generally decreased. When the critical temperature threshold for osteonecrosis was set at 47°C, none of the processes exceeded this, except for the ⌀2.0 drill.

Simplified drilling under low-speed without irrigation

There was no relationship between the diameter of the drill and the measured temperature distribution in the simplified drilling group. When comparing the steps omitted at the same drill diameter, it was found that omitting more steps in the process led to the generation of more heat. When 3 steps (⌀3.0, ⌀3.2, and ⌀3.8) before ⌀4.3 final drilling were omitted, the most heat was generated at (50.57°C ± 0.71°C), which exceeded the critical temperature for osteonecrosis.

Sequential drilling versus simplified drilling

Statistically significant differences between the sequential drilling group and the simplified drilling group at all diameters (P<0.001) (**Figure 3**). In addition, statistically significant differences were also observed in each simplified drilling group and according to the steps

https://doi.org/10.5051/jpis.2201400070

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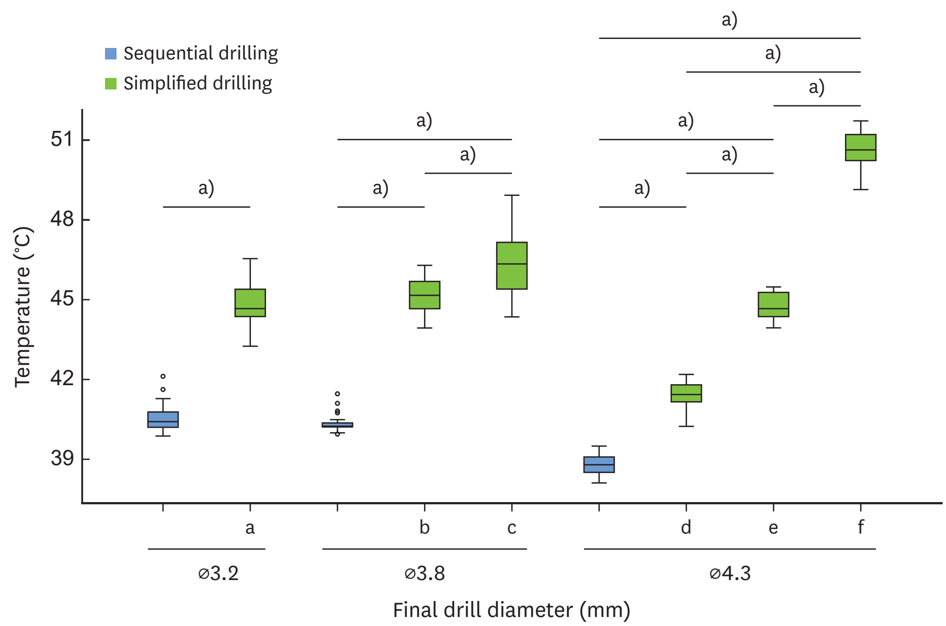

Figure 3. Box plots of temperature changes and corresponding comparison after sequential and simplified drilling according to the final drill diameter (⌀3.2, ⌀3.8, ⌀4.3mm). *P*-values less than 0.05 were regarded as statistically significant.
a: ⌀2.7→⌀3.2, b: ⌀2.7→⌀3.0→⌀3.8, c: ⌀2.7→⌀3.8, d: ⌀2.7→⌀3.0→ ⌀3.2→⌀4.3, e: ⌀2.7→⌀3.0→⌀4.3, f: ⌀2.7→⌀4.3.
a)$P < 0.001$.

omitted. Omitting more steps at the same diameter resulted in a higher average temperature change. Even when the same number of drills was omitted in the middle, omitting a larger-diameter drill led to larger temperature changes being observed.

DISCUSSION

As implant treatments have become more popular and are widely used, attention is now being paid to making the implant treatment process more comfortable. In this trend, guided implant surgery has been widely used in recent years and various surgical concepts have been combined with it. For the convenience of the patient and the surgeon, low-speed drilling without irrigation has been proposed and used widely in guided implant surgery. The aim of this study was to investigate the simplification of the implant drilling process in low-speed drilling to ease the surgical procedure. In other words, the goal was to evaluate whether the heat generated when the process of drilling was simplified under low-speed, water-free conditions was clinically acceptable. According to the results of our study, the mean temperature at most diameters with continuous drilling was lower than the critical temperature threshold for osteonecrosis of 47°C. Similar results were observed in other studies. Kim et al. [21] measured temperature changes using infrared thermography by performing high-speed drilling (1,200 rpm) and low-speed drilling (50 rpm) on pig ribs without water-cooling *in vitro*. They reported that drilling at 50 rpm without irrigation did not produce overheating. Similar results have been reported in experiments using artificial bone blocks with uniform cortical bone instead of animal bone, suggesting that low-speed drilling without irrigation does not cause overheating [27]. According to the histological analysis of an *in vivo* study, implant site preparation on bone by low-speed drilling (50 rpm) without irrigation and conventional drilling (800 rpm) under abundant irrigation were similar, and

https://doi.org/10.5051/jpis.2201400070

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both surgical drilling techniques preserved bone-cell viability [18]. Based on the above results, it can be considered that drilling at a low speed without water is clinically stable.

In this study, the critical temperature of 47°C was only exceeded when using the ⌀2.0 drill with an average temperature of 55.78°C. It is known that the ⌀2.0 drill has a higher temperature during drilling than other diameters [28,29]. In actual clinical practice, the temperature change is considered to be less than that observed in the experiment because there is a preceding process (e.g., a pilot drill) to mark the implant placement position in the cortical bone before ⌀2 drilling. In addition, the necrotic area due to surgical trauma has been reported as a 0.5-mm border [30]. The high average temperature in ⌀2 drilling does not cause any problems clinically because 0.5 mm is a margin that can be sufficiently removed through the subsequent drilling process.

Various drilling protocols have been introduced, including progressive drilling, single drilling, and simplified drilling. The optimal drilling protocol is not yet clear, and a variety of different methods can be presented through the modification of conventional sequential drilling methods. In this study, unlike previous studies, the middle step or several steps were omitted in the conventional sequential implant drilling, and this was compared with the sequential drilling. The experimental results show that the simplified drilling exhibited a significant difference in terms of the mean temperature change as compared to sequential drilling. The results of this study are similar to those of Möhlhenrich et al. [31], who reported that single drilling in D1 and D2 bone produced more heat than conventional drilling. However, in our study, all groups showed an average temperature within the limit temperature of 47°C, except when the previous 3 drilling steps were omitted in ⌀4.3 drilling. In this study environment, the initial temperature of the artificial bone block was set at 31.5°C±1°C, which was higher than in previous studies. We also tried to minimize the thickness left between the artificial bone and the final drill to maximize the accuracy of heat measurements and to make them constant for each experiment. For this purpose, the position of the initial drilling was calculated and marked for each drill diameter. It is thought that the thermal measurements were more accurate than those of other experiments. Therefore, the average temperature in our study was generally higher than reported in other studies.

Omitting a greater number of previous drilling steps within the same drilling diameter resulted in a greater average temperature difference. In ⌀3.8 drilling, the average temperature gradually increased in the following order: sequential drilling, 1 step (⌀3.2) skipped drilling, 2 steps (⌀3.0, ⌀3.2) skipped drilling. The same pattern was observed in ⌀4.3 drilling. Furthermore, a larger difference in width between the final drilling and the previous drilling was associated with a greater average temperature difference. According to the results of this study, the average temperature in the simplified drilling process is affected by the number of skipped steps and the drill diameter. Jimbo et al. [32] reported the combined effect of the drilling sequence (conventional vs. simplified: pilot drill + final diameter drill) and diameter *in vivo.* Histologically, they observed that the simplified drilling method had no signs of thermal osteonecrosis or excessive inflammatory response in any implants used in the experiment, regardless of diameter. After 5 weeks, there was no significant difference in bone-to-implant contact and bone area fraction occupancy between the 2 groups. In general, at week 5, when the initial bone remodeling is completed, most of the necrotized bone that may have occurred due to possible damage during the drilling process is replaced with new bone. This means that the heat generated when the simplified sequence is used does not have a decisive effect on the process of bone healing. However, we conducted drilling under low-speed conditions without water, and especially when using the ⌀4.3 drill after the ⌀2.7 drill, the measured mean highest temperature exceeded the critical temperature. According to a study, a single-drill protocol with a slow drilling speed (50 rpm) without irrigation led to temperature increases at the coronal and apical levels of the D4 bone, but not exceeding the critical temperature that could cause bone necrosis [33]. However, in that experiment, a D4 density bone block was used, and the diameters of the drills used were 3.4 mm and 3.6 mm. Therefore, when performing low-speed drilling without water in D1 density bone, as the diameter of the drill increases, a careful approach is needed to determine how many steps can be omitted in the previous stage.

In this study, D1 density artificial bone block was used to create the conditions that maximized heat generation. In a simplified drilling protocol, consideration of bone quality is needed to determine whether to skip a few steps in the process. In a recent study, single drilling and gradual drilling were compared according to bone density [31]. In contrast to previous studies, they reported that single drilling in D1 and D2 artificial bones generated more heat than conventional sequential drilling. In particular, conventional drilling was less likely to generate heat when the bone quality was low. Not only the diameter of the drill, but also the density of the bone affected the temperature change. The effects of single drilling and conventional drilling on the temperature change were different depending on the density of the bone. Since heat generation during drilling can lead to different outcomes depending on bone quality, further experiments in various bone densities may be needed to evaluate the stability of simplified drilling.

In conclusion, the results of this study show that simplified drilling produced more heat than conventional sequential drilling under low-speed (50 rpm) water-free conditions. However, since most of the simplified drilling groups had an average temperature within the critical temperature of osteonecrosis, it may be meaningful to use this technique in appropriate clinical settings. If clinically appropriate, guided implant surgery through simplified drilling under low-speed drilling and water-free conditions will be beneficial for patients' and operators' convenience. We excluded the length of the drill and did not consider the bone density, so in the future, experiments to reinforce the findings in this regard will be necessary. Since more friction is expected to occur as the length of the drill is longer, it will also be necessary to additionally evaluate the clinical application of simplified drilling under low-speed water-free conditions for the commonly used drill lengths. Future research will be needed to establish the relationship between heat generation and biomechanical parameters to measure osseointegration in order to establish an optimal surgical drilling protocol.

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