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Effect of Implant Drill Characteristics on Heat Generation in Osteotomy Sites

- A Pilot Study -

임플란트 드릴링 시 열 발생에 대한 드릴 특성의 효과

- 선행 연구 -

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치의학과

오 현 준

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지도교수 구 기 태

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치의학과
오 현 준

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위 원 장 설 양 조 (인)

부위원장 구 기 태 (인)

위 원 이 용 무 (인)

Abstract

Objectives: The objective of this study was to evaluate the effect of drill-bone contact area on bone temperature during osteotomy preparation.

Material and Methods: Conventional triflute Ø3.6 mm drills were modified with the intent to reduce frictional heat induction. The peripheral dimensions of the drill were reduced 0.15, 0.35 and 0.50 mm to evaluate the effect of surface area on induction of frictional heat between the drill and bone/cutting debris (Parameter A). Also, the lateral cutting surface of the drill was set to 0.1, 2.0 and 7.5 mm to estimate heat induced by direct function of the drill (Parameter B). A non-modified triflute drill (parameter A: 0 mm; parameter B: 15 mm) served as control. Thus 9 drills with different A/B combinations versus 1 control were tested in artificial bone. Real time temperature changes (during drilling and withdrawing) were assessed using an infrared thermal imager. Each drilling procedure was performed up to 20 times. Thermal image data was transferred to a PC for simultaneous analysis.

Results: Mean temperature changes for all modified drill combinations were smaller than for the control ($P<0.001$). The effects of parameters A and B were statistically significant ($P<0.001$). There was a significant interaction effect between the two parameters ($P<0.001$) showing that the effect of parameter A on the mean temperature changes is different depending on the values of parameter B. As the dimensions of parameter B decreased, the temperature change during drilling also decreased. However, a tendency for the temperature to increase or decrease by parameter A was not observed.

Conclusions: Within the limitations of this pilot study, the observations herein suggest that reduction in contact area between the drill and bone reduces heat induction. Further studies to optimize drill/bone contact dimensions are needed.

Keywords : implant drill design, surface contact area, frictional heat
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1. Introduction

One factor critical to the success of dental implant osseointegration is the avoidance of thermally induced necrosis at the osteotomy site (Eriksson & Albrektsson 1983; Brisman 1996). Thermally induced necrosis as a result of elevated temperatures from osteotomy preparation has been reported, and exposure to a temperature of 47°C for 1 min is thought to represent an upper threshold for bone survival (Eriksson & Albrektsson 1982; 1983; 1984). Factors that contribute to induction of frictional heat include the design and size of the drill bit, the force applied, the speed and the sharpness of the drill, and application of a coolant (Tehemar 1999). Moreover, heat generation varies with osteotomy location (Watanabe et al. 1992; Yacker & Klein 1996).

A study using bovine bone blocks demonstrated that the temperature increase recorded with the 3.3 mm triflute drill was significantly smaller than that obtained with the 2 mm twist drill, despite the fact that the implant sites were not already cut by any preceding smaller-diameter burs (Cordioli & Majzoub 1997). The smaller temperature increase generated by the triflute drills may be attributed to their shape enabling effective elimination of cutting debris while reducing frictional resistance. Less heat generation usually accompanies drills with larger compared with smaller diameters. This may be the result of normally practiced graduated sequential drilling. Since substantial amounts of bone have already been removed in the preceding sequences with smaller diameter drills, the larger diameter drills are subject to cut less bone thus resulting smaller temperature increases. Drill geometry may also play a major role in heat generation. Increased temperatures have been observed for systems that lack relief angles and have small clearance angles (Chacon et al. 2006). Smaller relief angles increases bone contact resulting in increased frictional heat.

One aspect that has received limited emphasis is the influence of contact area between drills and bone on heat induction during osteotomy preparation. The following hypothesis was proposed. As the contact area between the drill and bone is reduced, it is expected to reduce friction thereby inducing less heat. These effects have not been studied. Therefore drills with a modified design were used to evaluate the effect of contact area reduction on bone temperature changes during osteotomy preparation.

2. Material and Methods

2.1 Drill design

Conventional triflute Ø3.6 mm drills (Osstem Implant Inc., Busan, Korea) were modified with the intent to reduce induction of frictional heat. The design modifications are shown in Figures 1 and 2. Changes were defined as parameters A and B. For parameter A, the peripheral dimensions of the drill were reduced 0.15, 0.35 and 0.5 mm. These reduced dimensions were tested to evaluate the effect on induction of frictional heat between the drill and bone/cutting debris. Parameter B relates to heat generated by direct function of the drill. For this study, the lateral cutting surface of the drill was set to 0.1, 2.0 and 7.5 mm. Also, the “rake angle” defined as the angle between the leading edge of a cutting tool and a plane perpendicular to the surface being cut was set to be positive. Thus, nine drills with different parameter A/B combinations were manufactured and assigned as experimental groups 1-9 (Table 1, Figure 3). A non-modified Ø3.6 mm triflute drill (parameter A: 0 mm; parameter B: 15 mm) served as control (group 0). These ten drill designs were compared to evaluate the effect of the surface area reduction on induction of frictional heat.

2.2 System configuration

The overall experimental setup included the modified drills, artificial bone blocks providing a uniform platform (Sawbone, Pacific Research Laboratories, Inc., Vashon, WA, USA), a drilling system (Hangil, Suwon, Korea), and an infrared thermal imager (IRI 1001E, Irisys, Northampton, UK). The bone blocks were soaked in a water bath at 60℃ for 3 h to produce an internal temperature of 37℃ (human body temperature). A coolant was not employed for explicit comparison. The laboratory temperature was kept at 30 ± 1°C using thermostatic temperature control.

2.3 Temperature measurement system

Bone temperature registrations were performed at selected sites on the bone blocks. The temperature changes were assessed using the thermal imager (range: -20 - 300°C; sensitivity: 0.5°C; accuracy: 0.05°C). Since infrared thermography measures heat radiating from a surface, the distance between the thermal imager and the lateral surface of the bone blocks was kept to a minimum of 80 mm. In addition, the distance from the lateral border of the bone block to the drilling path was set to 0.3 mm since temperature decreases were observed in areas exceeding 0.3 mm (Figure 4). The drilling depth of

15 mm was divided into 6 areas of interest each measuring 2.7 x 2.7 mm. The temperatures were measured in real time during drilling and withdrawing (Figure 5). The maximum bone temperature was regarded as the experimental result. Thermal image data was transferred to a PC for simultaneous analysis.

2.4 Operational procedure

Drill speed was maintained constant at 1,500 rpm with a constant load of 4 ± 1 N using a drill press with an automated regulatory feedback system (Figure 6). This customized automated system produced a constant load of 4N by measuring the drilling load at the load cell and regulating the drill speed through the actuator using the regulatory feedback system. Continuous drilling was executed to a depth of 15 mm with a drilling time of 2.0 ± 0.1 sec for drilling and the same for withdrawing, respectively. A preliminary experiment was conducted to choose an optimal drilling sequence. Figure 7 shows the tested drilling sequences in quintuplicate repeats. Since the maximum temperature change was observed in the 3.0-3.6 mm interval, the diameter of the drills for evaluation was set to 3.6 mm. Therefore, after drilling using a 3.0 mm drill, the 3.6 mm drills assigned to the 10 groups were tested. Each drilling procedure was performed up to 20 times.

2.5 Statistical analysis

Temperature changes were summarized using means and standard deviations. To compare mean temperature changes between the control and experimental groups, a one-way ANOVA was used, followed by the Tamhane test for a post-hoc analysis.. A two-way ANOVA was used to analyze the effect of parameters A and B on mean temperature change. Statistical analysis was performed using the SPSS 13.0 software program.

3. Results

Mean temperature changes following bone drilling are presented in Table 2 and Figure 8. The one-way ANOVA revealed that there were statistically significant differences among the control and the experimental groups (*P*<0.001). The mean temperature changes for all experimental groups were smaller than for the control. Group 4 with parameter A at 0.35 mm and parameter B at 0.1 mm showed the smallest mean temperature change that was statistically significant compared to all other groups.

Thermal changes by parameters A and B are illustrated in Figure 9. The two-way ANOVA showed that there was a statistically significant interaction effect between parameters A and B (*P*<0.001). As seen in Figure 9, the effect of parameter A on thermal changes was different depending on the values of parameter B. The main effects of both parameters were also statistically significant (*P*<0.001). As the dimensions of parameter B decreased, the temperature change during drilling also decreased while a tendency for the temperature to increase or decrease by parameter A was not observed. Parameter A at 0.35 mm showed the smallest mean temperature change reaching statistical significance compared with parameter A at 0.15 and 0.50 mm.

4. Discussion

Studies evaluating factors that influence temperature during osteotomy preparation have focus on drilling depth (Wiggins & Malkin 1976), drilling speed (Abouzgia et al. 1995), drilling time (Reingewirtz et al. 1997), sharpness of the drill (Matthews & Hirsch 1972), pressure applied to the drill (Matthews & Hirsch 1972) and irrigation (Benington et al. 2002; Sener et al. 2009). The present study focused on the contact area between the drill and bone testing the hypothesis that reducing the contact area will induce less frictional heat. Using a conventional 3.6 mm triflute drill, contact area reductions were implemented at two aspects of the drill, the peripheral dimensions (parameter A) and the dimensions of the lateral cutting surface directly contacting the bone (parameter B). The results suggest that reducing the contact area between the drill and bone reduces heat generation. The control where changes of parameter A and B were not incorporated showed a statistically significant increase in mean temperature compared to the nine experimental groups. This finding validates our hypothesis. However, since the parameters used in the present study have not been evaluated previously, it is imperative that the effect and value of the two parameters used in the present study, A and B, be explained in detail.

The rationale behind the evaluation of parameter A was to test whether reducing peripheral dimensions of the drills would have an impact on induction of frictional heat. As the drill rotates and penetrates the bone, chips are formed which are channeled along the flutes of the drill away from the cutting edge. As a result, these bone chips may remain in the bone cavity during drilling producing a contact surface with the periphery of the drill. Thus, drills with smaller peripheral dimensions were thought to have smaller contact area with the bone chips resulting in less frictional resistance and heat produced. However, the results of the present study failed to show a tendency of parameter A affecting the thermal changes during the drilling process. Although the mean temperature changes were statistically significant, the three reduced dimensions did not generate a consistent pattern in temperature reduction. Only parameter A at 0.35 mm showing the smallest mean temperature change was statistically significant. One reason for this may be due to the limited number of parameter A as only three variables 0.15, 0.35, and 0.50 mm were evaluated. Another reason may relate to the inconsistent pattern of bone chip removal. During drilling, the bone chips were removed randomly with no consistency in direction and rate of removal. Also, the use of triflute drills in the present study rather than twist drills or more precisely, biflute drills, may have impacted the results. As previously reported easier elimination of the cutting debris was observed with 3 mm triflute drills compared to 2 mm twist drills resulting in less frictional resistance and temperature rise (Cordioli & Majzoub 1997). Thus, to find a more discrete effect of parameter A, further studies using additional variables should be considered.

Parameter B was immediately related to heat induction; the drill-bone contact area being proportional to the size of parameter B. The larger parameter B created a wider contact area between. We recorded greater temperature increases while drilling with larger parameter B. Although direct comparison is difficult, the principles behind these results are in agreement with some previous work (Chacon et al. 2006). Increased surface in contact with the bone resulted in increased frictional heat. Nevertheless, further studies are necessary to confirm the ideal dimensions of parameter B. Factors such as irrigation to simulate the exact clinical conditions need to be employed in successive experiments as well.

One aspect that has not been discussed is the cutting efficiency of the drills after incorporating parameters A and B. In a previous study (Ercoli et al. 2004), it was reported that drill design can significantly affect cutting efficiency and durability resulting in elevated bone temperatures. Thus, if one assumes that changes in parameters A and B reduced cutting efficiency of the drills, the results of the present study may be questioned as an increase in bone temperature should have been the expected outcome. However, since cutting efficiency was not evaluated, it is difficult to draw any conclusions and the reasons for the results may only be speculated. It may be indirectly suggested that since changes were made only to the lateral region of the drill, cutting efficiency may not have been compromised. Also, reductions in the periphery may have contributed more substantially in reducing frictional heat than anticipated. More studies directly correlating the changes in parameter A and B with cutting efficiency are needed to draw a conclusion.

Another aspect that needs to be discussed is the applicability of parameters A and B to clinical use. A significant amount of vibration and instability was observed during drilling in the present study. This phenomenon may be attributed to the enlarged tips as a result of peripheral reductions which in a way tended to ovalise, making it difficult to produce cylindrical bores. Thus, more efforts are in need to ascertain the following: a consistent pattern in temperature reduction of parameter A, the ideal dimensions of parameter B and a critical limit in the peripheral reduction to prevent the ovalisation phenomenon. Also, addition of more flutes may be considered for clinical use. The advantage of having an extra flute in the drill design may be the enhanced cutting efficiency. However, it is our belief that the triflute drill is more stable during drilling and produces less frictional heat. More flutes in the design may narrow the channels of the flutes that function as a path for bone chip removal. As the effective elimination of the bone chips are hampered, bone chips will accumulate to some extent in the channels eventually resulting in impaired cutting efficiency and elevated frictional heat.

There is no data in the literature to support this however; thus more research is needed concerning the optimal number of flutes and its effect on stability, cutting efficiency, and frictional heat.

Finally, the longevity of drills after incorporating parameters A and B merits discussion. The longevity of a drill can be affected by two factors: the wear of the cutting part and fracture or bending of the drill in the periphery. Since the cutting part remained untouched and minor reductions of 0.15, 0.35, and 0.5 mm were made only to the periphery leaving the core of the drills intact, it is difficult to conclude that parameter A had an impact on longevity of the drills. However, incorporation of parameter B creates a step in the lateral cutting surface of the drill, making it weaker and vulnerable to physical strain and fracture. Future studies should focus on longevity and durability of drills as well.

5. Conclusion

Within the limitations of this pilot study, the observations herein suggest that reduction in contact area between the drill and bone reduces heat induction. Further studies to optimize drill/bone contact dimensions and applicability to clinical use are needed.

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Tables

Table 1. List of experimental groups with different combinations of parameter A and parameter B

Parameter B (mm) Parameter A (mm)	0.1	2.0	7.5
0.15	Group 1	Group 2	Group 3
0.35	Group 4	Group 5	Group 6
0.50	Group 7	Group 8	Group 9

Table 2. Comparison of temperature changes of the ten groups that were evaluated

Group	0	1	2	3	4	5	6	7	8	9
Mean temperature before drilling (°C)	31.67	31.30	32.07	31.64	31.88	31.89	31.62	32.03	31.89	31.24
Mean temperature after drilling (°C)	40.57	35.08	37.79	37.90	34.14	37.95	37.38	35.44	36.99	37.84
Mean temperature change(°C)	8.90	3.78	5.72	6.26	2.27	6.06	5.76	3.40	5.10	6.60
Standard deviation of temperature changes	1.05	0.28	0.67	0.53	0.26	0.59	0.36	0.28	0.45	0.75

Figures

Figure 1. Conceptual design of the drills. Parameter A represents reductions of the peripheral dimension. Parameter B represents drill-to-bone surface contact area. The diameter of the drills was set to 3.6 mm.

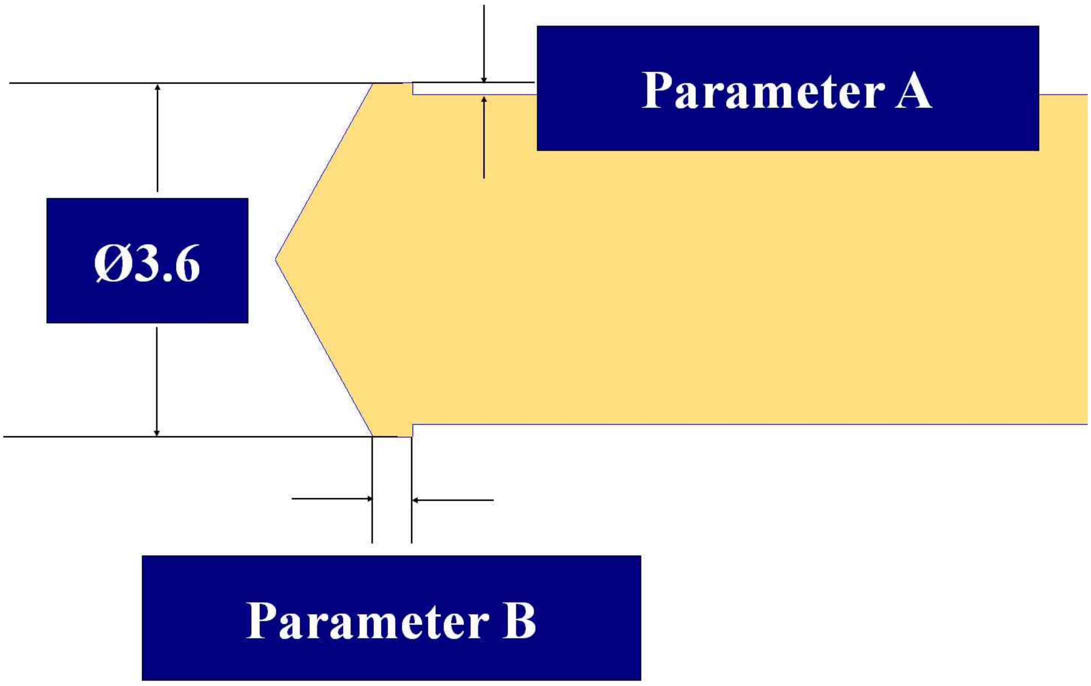


Figure 2. Illustration of the modified drills. (a) Lateral view of the drill showing parameter B. (b) A view from the bottom of the drill showing parameter A and the triflutes. (c) A transverse section showing the reduced peripheral dimensions. (d) Illustration of the positive rake angle and relief angle which is equivalent to clearance angle in the drills used in the present study.

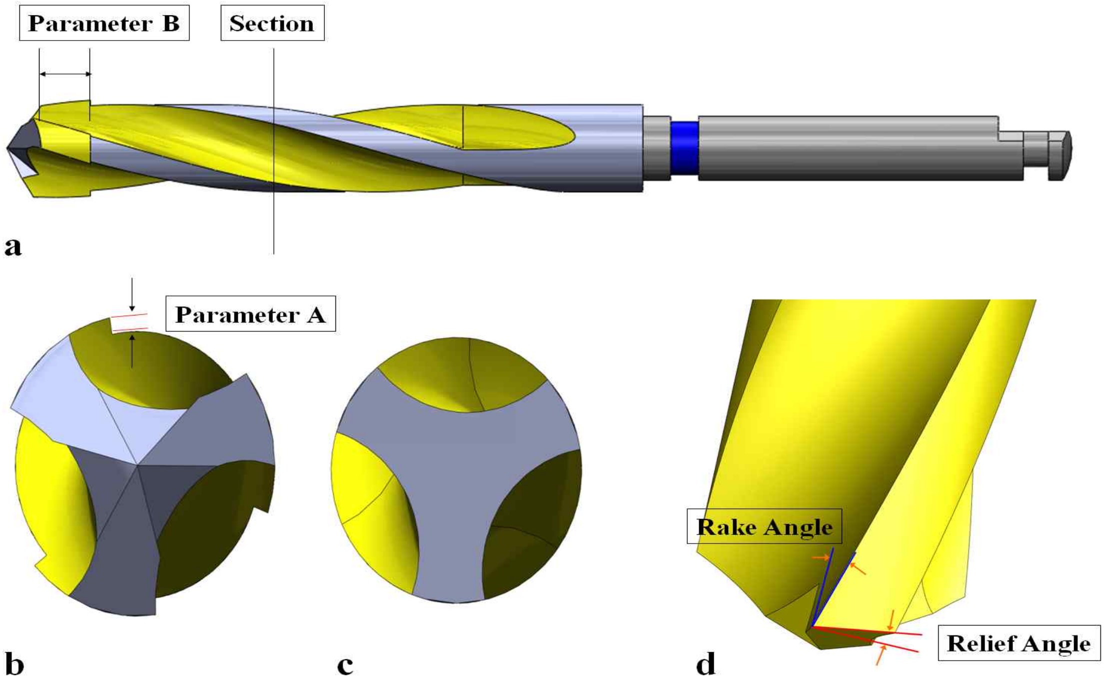


Figure 3. Modified drills. (a) Left-right: parameter A was set to 0.15, 0.35 and 0.5 mm, and top-bottom parameter B was set to 7.5, 2.0 and 0.1 mm. (b) High magnification of experimental drill, note the reduced parameter B dimensions that directly contact bone.

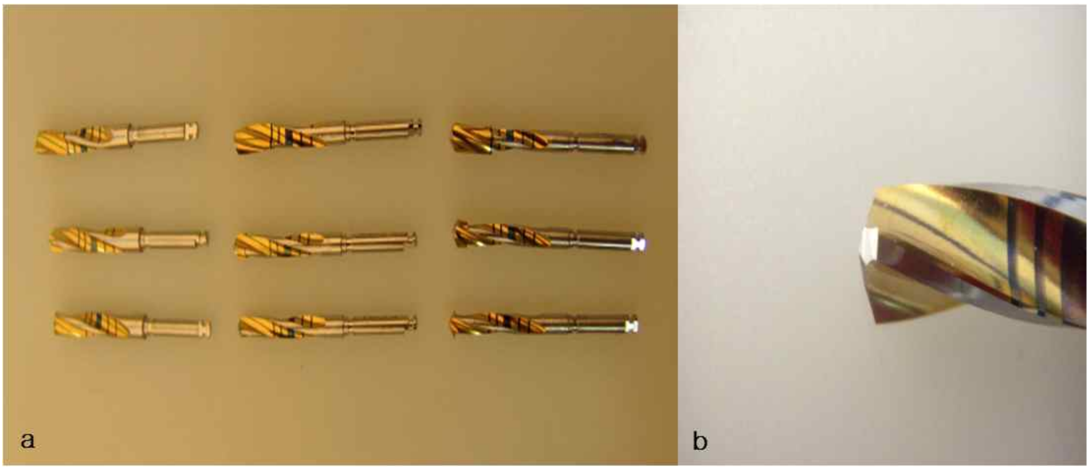


Figure 4. Temperature changes according to the distance from the lateral border of the bone block to the drilling path. Temperature decreases were observed in sites exceeding 0.3 mm.

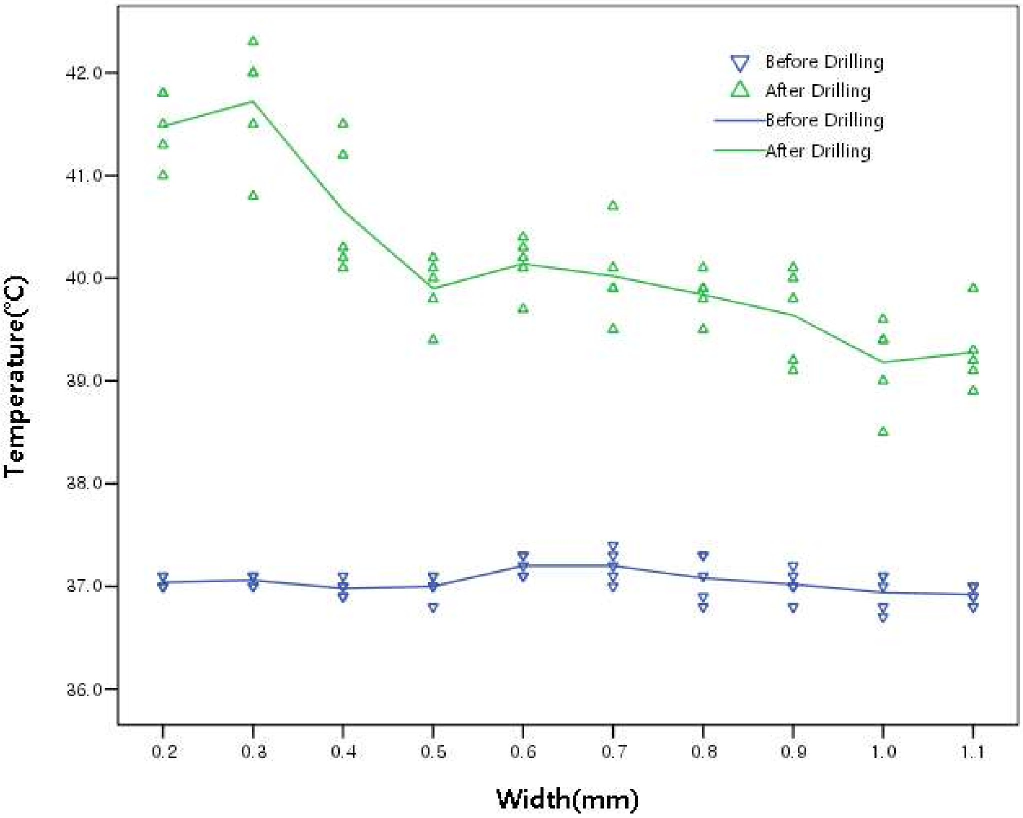
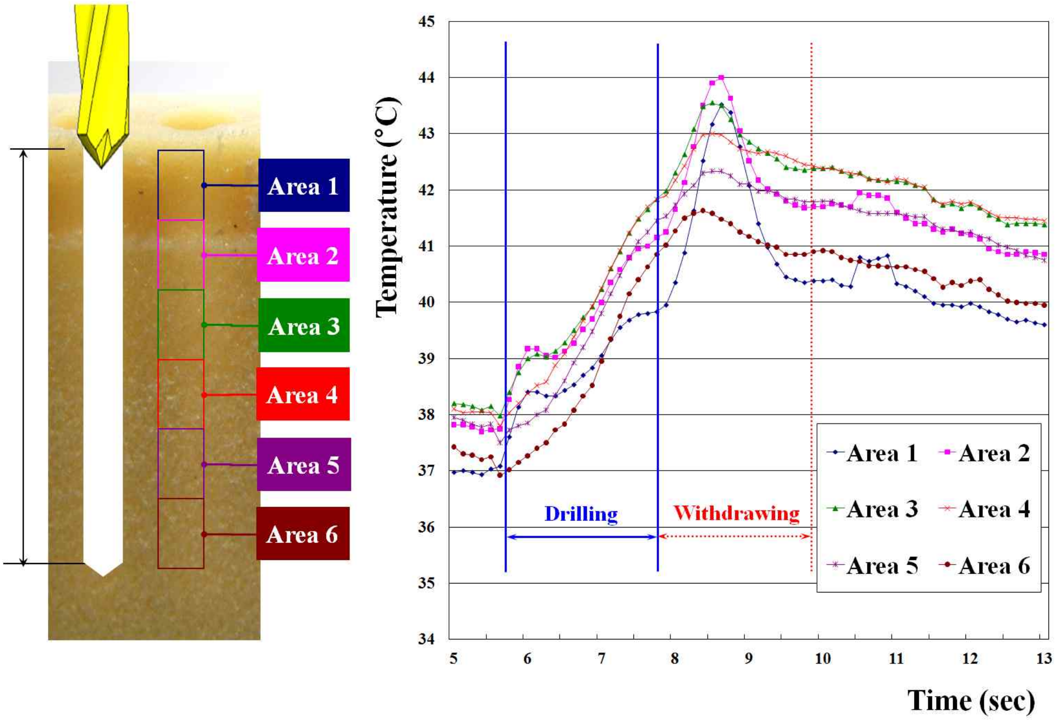


Figure 5. Temperature recordings. (a) Temperature recording sites with 15 mm drilling depth were divided into 6 areas of interest. (b) Illustration of temperature changes when drilling and withdrawing. Temperatures were measured in real-time.



a

b

Figure 6. Illustration of a customized automated drill press system to produce a constant load of 4N by measuring the drilling load at the load cell and regulating the drill speed through the actuator using the regulatory feedback system.

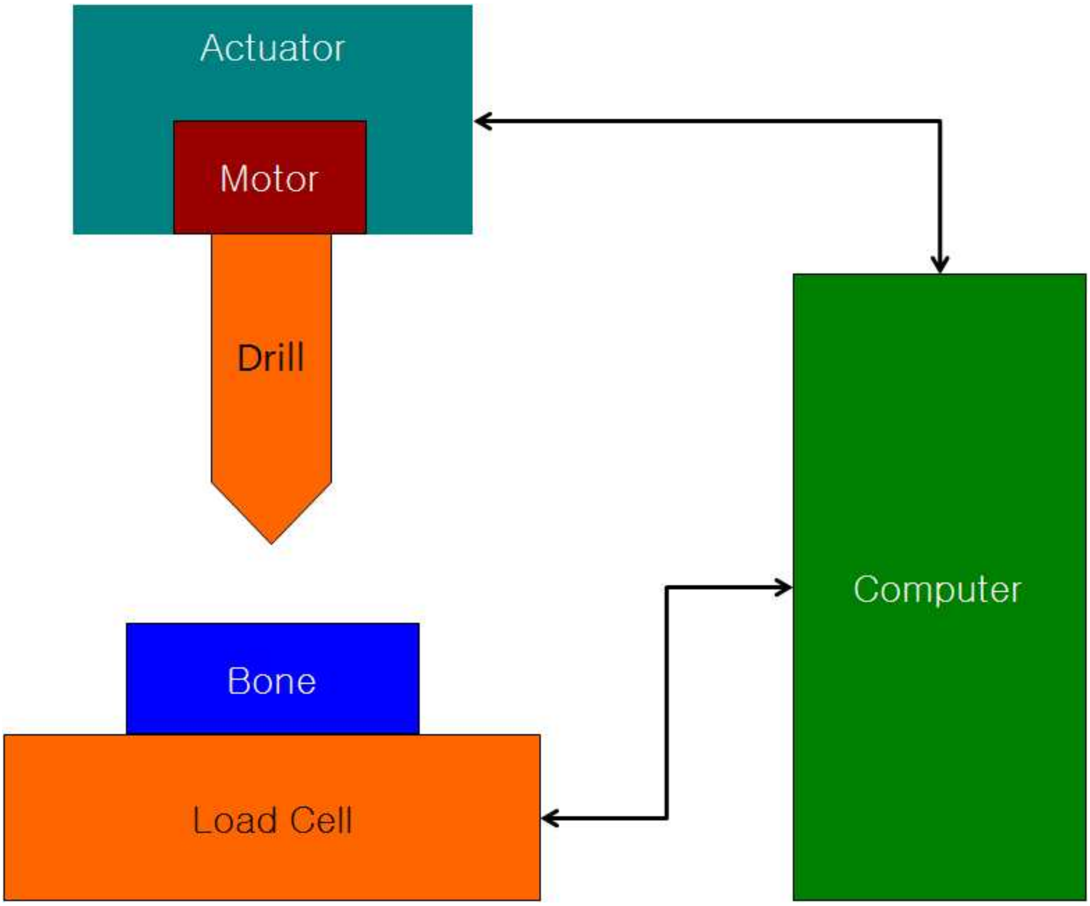


Figure 7. Results of preliminary experiment determining the drilling sequence. The maximum temperature change was observed in the 3.0-3.6 mm interval.

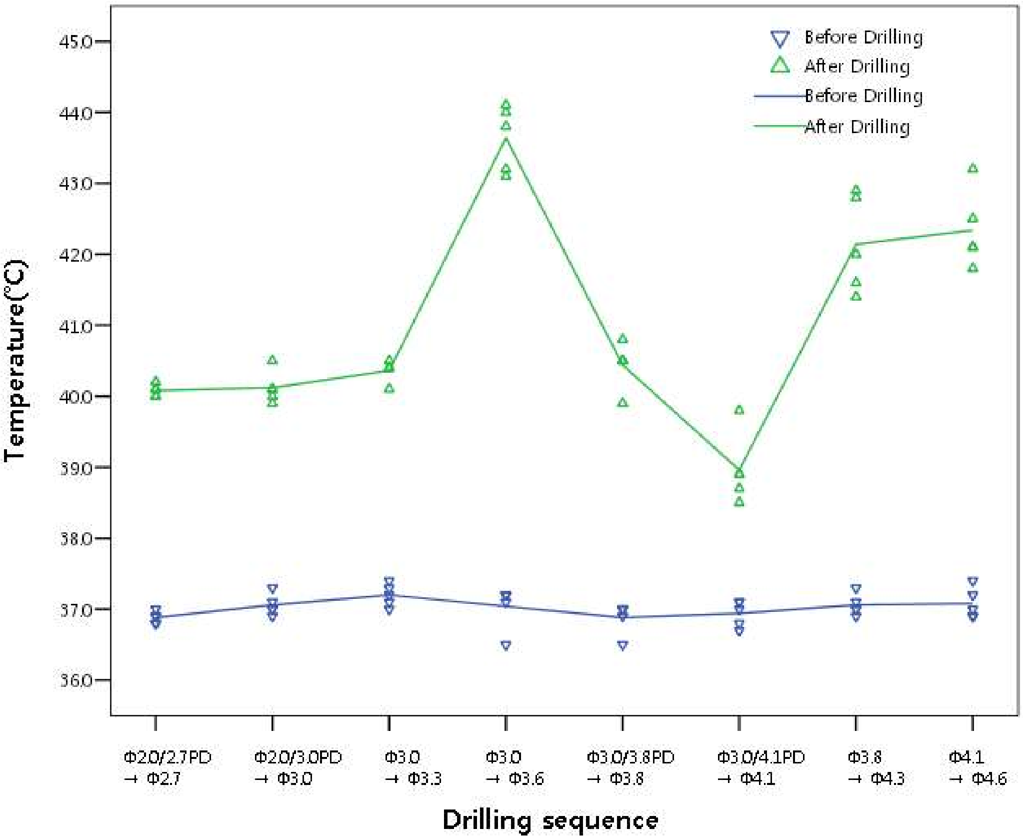


Figure 8. Mean temperature changes by group (0-9).

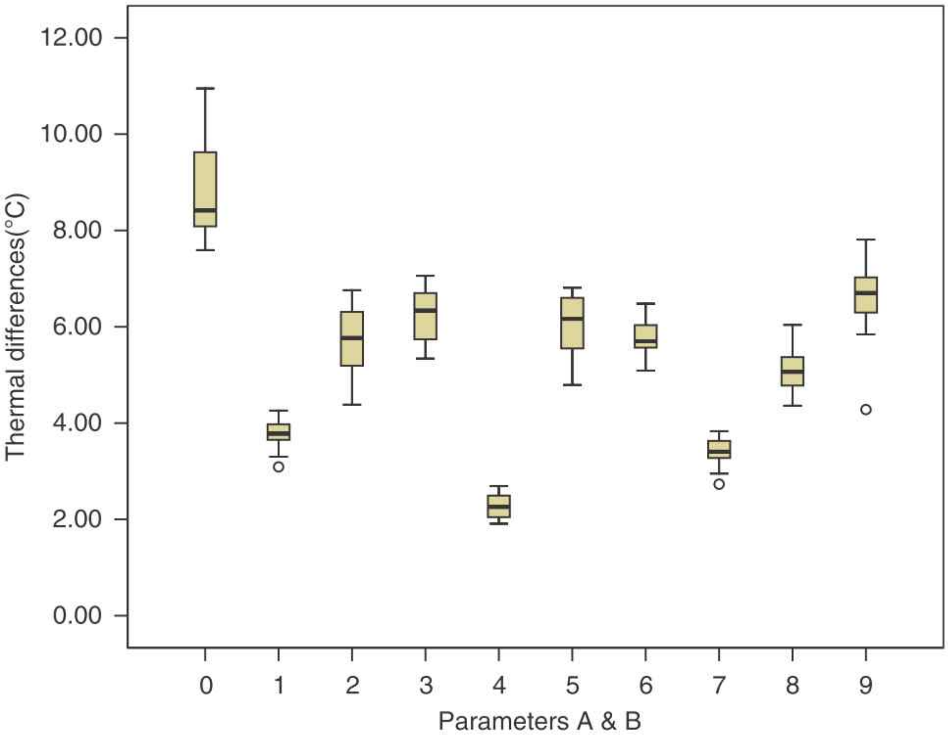
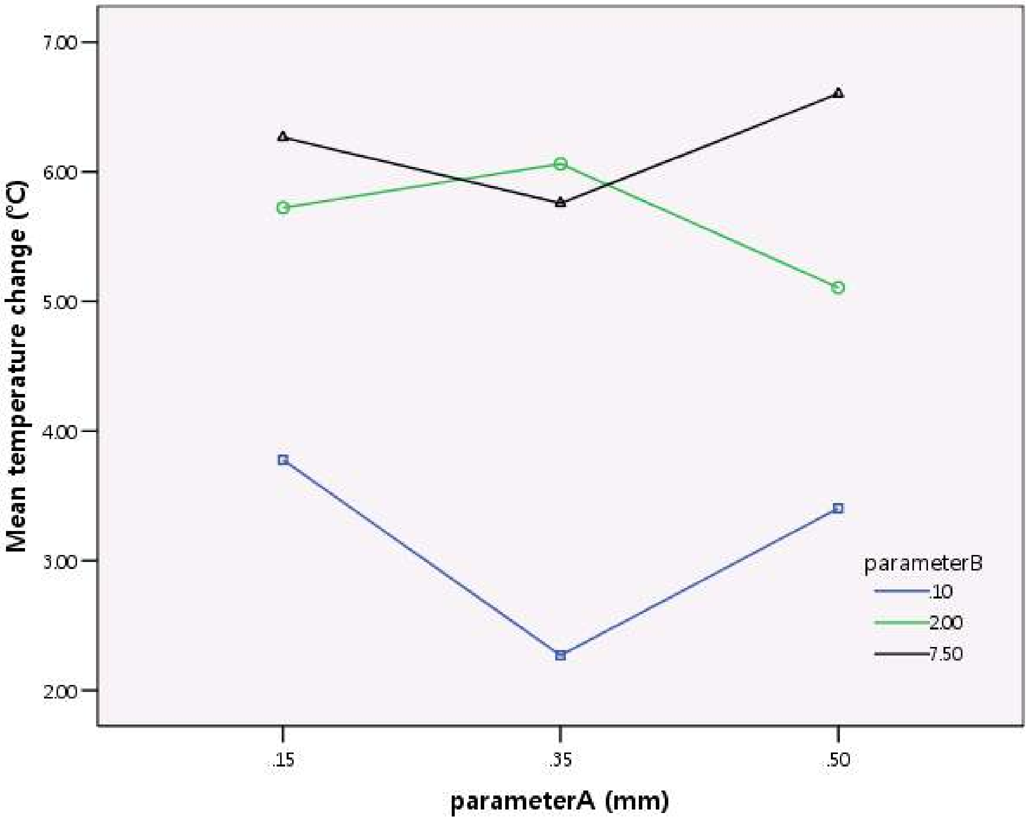


Figure 9. Thermal changes by parameters A and B.



국문초록

임플란트 드릴링 시
열 발생에 대한 드릴 특성의 효과

오현준
치의학과
치의학대학원
서울대학교

목적: 본 연구의 목적은 임플란트 드릴링 과정에서 드릴과 골 간 접촉면이 골 온도에 미치는 영향을 평가하기 위함이다.

방법: 마찰열 발생을 감소시키기 위해 기존의 Ø3.6 mm의 세 날 드릴을 개조하였다. 드릴과 절삭된 골 파편 사이에 발생하는 마찰열에 대해 드릴 표면적이 미치는 효과를 평가하기 위해 드릴의 주변부 직경을 0.15, 0.35, 0.50 mm 씩 감소시켰다 (매개변수 A). 또한 드릴과 골 간 직접 접촉에 의한 열 발생을 평가하기 위해 측면 절삭면을 0.1, 2.0, 7.5 mm로 설정하였다 (매개변수 B). 기존의 세 날 드릴을 대조군으로 사용하였다 (매개변수 A: 0 mm; 매개변수 B: 15 mm). 매개변수 A와 B의 아홉 가지 조합으로 구성된 실험군과 한 가지 대조군에 대해 인조골에서 실험하였다. 적외선 열화상 카메라를 이용하여 실시간으로

드릴링 과정에서의 온도 변화를 측정하였다. 각 드릴링 과정을 20번씩 수행하였다. 열화상 데이터를 즉시 PC로 전달하여 동시에 분석하였다.

결과: 제안한 모든 드릴의 평균 온도 변화는 대조군의 평균 온도 변화보다 작았다 ($P<0.001$). 매개변수 A와 B의 효과는 통계적으로 유의하였다 ($P<0.001$). 매개변수 A가 평균 온도 변화에 영향을 미치는 효과가 매개변수 B의 값에 따라 달라지는, 두 매개변수 간 상호작용이 통계적으로 유의하였다 ($P<0.001$). 매개변수 B의 크기가 감소할수록 드릴링 시 온도 변화 역시 감소하였다. 그러나 매개변수 A의 크기에 따라 온도 변화가 증가하거나 감소하는 경향은 없었다.

결론: 본 선행 연구의 범위 내에서, 드릴과 골 간 접촉 면적이 작을수록 열 발생이 감소함을 알 수 있었다. 향후 드릴과 골 간 접촉 공간을 최적화하기 위한 연구가 필요하다.

주요어 : 임플란트 드릴 디자인, 표면 접촉면, 마찰열
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