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Measurement of temperature change during the implant site preparation to determine influence of tool characteristics

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ABSTRACT

Implant site preparation procedure is the most important factor that affects early osseointegration performance of a dental implant. During the side preparation procedure increase in the bone temperature above critic limit causes irreversible osteonecrosis. This heat rise compromises implant area around implants thus ending with unsuccessful osseointegration outcomes.

In this experimental study drill tip geometry, drill tip angle and drill sharpness affects on procedure temperature were investigated. Experiments were carried on fresh bovine bones and implant sites were prepared individually for each experimental set.

1. Introduction

Today different kind of dental implant surfaces, geometries and materials are being developed to overcome early implant failures and to lengthen implant duration in the mandible. Bone is an anisotropic material with organic and inorganic components. Also, its microarchitecture and density is changeable according to mechanical and physical affect such as loading conditions and hormonal affects [1–3]. There are numerous works focused on implant osseointegration performance to prevent implant failures. The following reports investigated effective factors for osseointegration performance by various authors: implant surface modification [4–8], implant materials [9,10], implant geometry [11,13], dental drills [12,14] and surgical technique [15,16]. All of these factors influence loosening of dental implant-bone interface, consequently osseointegration performance. Among these, dental drills and surgical technique has crucial effect on early osseointegration period. Determining optimum procedure parameters enables to decrease procedure temperature, prevent osteonecrosis and implant failures as well.

Implant site preparation procedure is a drilling procedure which causes friction and heat rise in the bone [17,18]. This friction and heat rise conduce osteonecrosis which result in problem during osseointegration and consequently mechanical misfits of dental implant [17]. During implant site preparation bone temperature must be below 47 °C to prevent necrosis [19,20]. Thermal damage to the cells in this area may cause failure and miss fixation of the implant. Implant success is strongly correlated with the quantity and quality of bone in the implant recipient site. From this point of view minimization of the heat rise in bone-implant interface increases osseointegration performance and decreases failure risks. In the literature there are studies for understanding the effect of factors to the implantation success by identifying favorable drilling conditions, bone behavior and drill geometries [14,21–26].

The aim of this experimental study is to obtain the relation between factors that will contribute to the

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temperature attained include drill tip angle, drill coating, usage duration of drill (drill sharpness and tip degenerations) and the application of coolant. The experimental design was made by means of Taguchi Method. Data were analyzed using descriptive statistics. Statistical analyses were conducted with ANOVA. The quality characteristics for analysis considered as lowest temperature during the procedure. After experimental study the optimum parameters are determined according to these analyze results.

2. Material and method

The experimental set up was built as close as real dental drill conditions as seen in Fig. 1. For this purpose a medical slow hand piece (NSK, Nakanishi Inc., Tokyo, Japan) and irrigation system were used. The drilling parameters were controlled by the slow hand piece. The constant movement of slow hand piece in the *y* direction was controlled by the computer with 5 mm/sn velocity. Cutting speed was 800 Rpm under constant torque automated by the slow hand piece. The irrigation system was provided from slow hand piece system with 20 ml/d. Sterile saline sodium chloride 0.9% solution (Eczacıbası Company, Istanbul, Turkey) was used. To observe precisely the effect of tool characteristics same cutting parameters were used. Furthermore *x*, *z* axes were fixed in the experimental set up (Fig. 1).

In the present study, three procedure parameters (coating, drill tip angle and usage of drill) with two and three different levels were used and are shown in Table 1.

Before every implant site preparation all of the thermo-couples were calibrated by a certificated company (TESTO Company, Istanbul, Turkey) according to the related standard *ISO*/IEC 17025 [27]. Linearity of the calibration curve was confirmed with a regression curve fit and used as calibration equation. Afterwards room temperature and bone temperature were recorded. 0.5 mm diameter holes with 1 mm depths from the surface were drilled

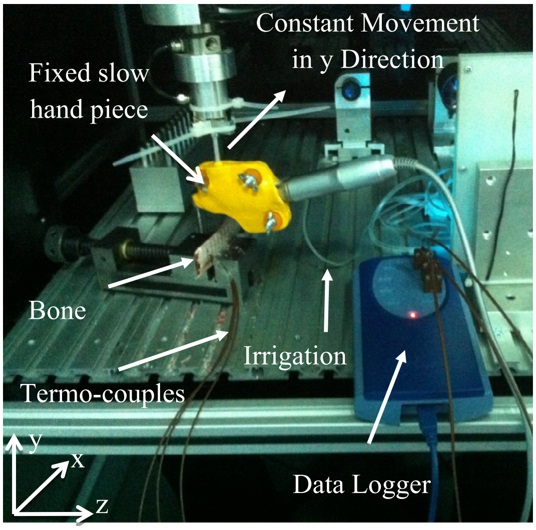

Fig. 1. Experimental set-up.

Table 1
Milling parameters and their levels.

Parameters	Parameter designation	Level 1	Level 2	Level 3
Coating	A	Coated	Uncoated	–
Drill tip angle (°C)	B	120	110	90
Usage	C	New	45 Times	90 Times

on fresh bovine bone for the placement of thermo-couples. The drills were inserted into the bone with 6 mm intervals. The thermo-couple places were prepared by means of 2 mm diameter burs (Fig. 2a and b).

The three thermo-couples were located parallel to the drill area vertically with 6 mm intervals (Figs. 2(a and b) and 3). During the drilling procedure temperature was measured from these three different points. Afterwards mean value of these three points was used as the output value. The holes and number of location for each thermo-couple can be seen in the cross-sectional view of the sample in Fig. 2(b).

Temperature rise of the bovine bone during the drilling was recorded with embedded t-type thermo-couples by a data logger (PicoTC-08 with the accuracy of the unit; sum of ±0.2% and 0.51 °C) which was connected to computer program. The rise of heat during the drilling procedures was recorded every 0.01 s time intervals. This facilitated the continuous monitoring of the temperature changes with small intervals that were produced within the bone at the interface. Maximum and minimum difference was taken as Δt, and used as the output value for the analyses that represents the heat change in the bone. Temperature measurements were recorded by the program with three digits after the decimal point.

Taguchi method is a widely used technique for determining parameters effect on selected quality characteristic and optimizing industrial/production processes. This method can be divided three stages; (1) Orthogonal array selection, (2) Parameters and their levels selection, (3) Experiments and statistical analysis according to experimental results. By mean of these analyses optimum conditions are identified. First two steps are crucial for accurately optimization of the procedure [28]. Using a specific orthogonal array decreases number of experiments compared to classical design approach. With the increase of the process parameters the number of experiments also increases with the combination of these parameters. Taguchi method proposed various combinations which decreases the number experimental sets and provides a proper parameter combination [28]. A loss function is defined by this method to calculate deviation between the experimental results and the expected quality. With statistical analyses this loss function is digitized into signal/noise (S/N) ratio by means of the determined quality characteristics i.e. the lower-the-better (LB), the higher-the-better (HB) and the nominal-the-better (NB) [28]. For our experiments, quality characteristic selected as the lowest process temperature for lowest temperature rise in the bone. In accordance with this purpose lower the better function was used for the analysis of the results. After determining the optimal levels of factors a statistical

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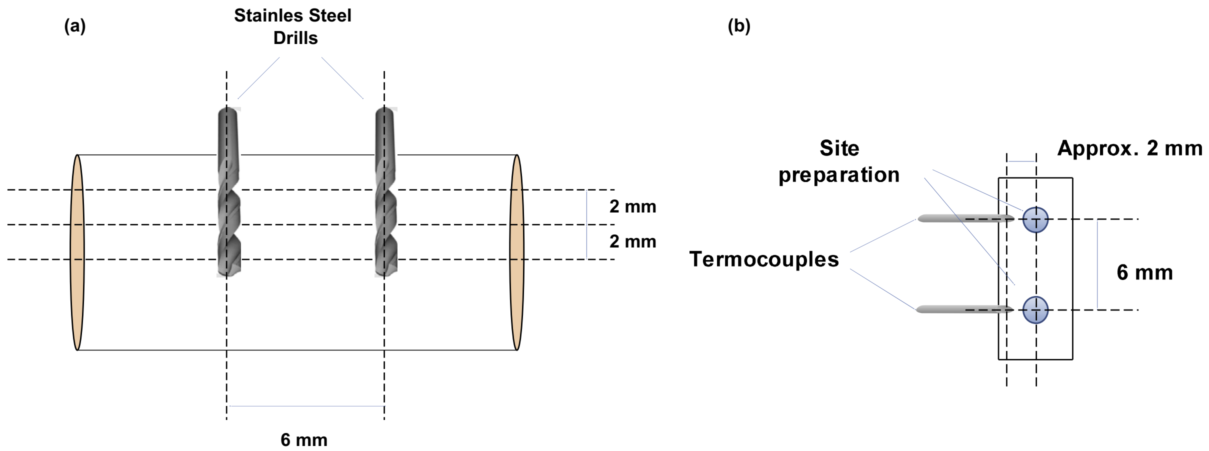


Fig. 2. Schematic draw of bone from (a) Front view and (b) Upper view.

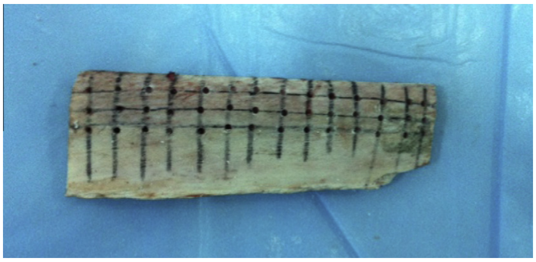


Fig. 3. Fresh bovine bone.

Analysis of Variance (ANOVA) was employed to determine the significant parameters. Furthermore with these results a final confirmation experimental set was made to verify the results according to these analyses.

The S/N ratios for each type of characteristics were calculated as follows (LB);

$$S/N = -10\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right). \quad (1)$$

Table 2
L18 (2x2^1, 3x2^2) mixed level orthogonal array and results with or without irrigation.

Run	Coating type	Drill tip angle (°)	Usage	With irrigation ΔT (°C)	Without irrigation ΔT (°C)
1	1	1	1	0.805	4.997
2	1	1	1	1.329	5.715
3	1	1	1	1.177	6.269
4	1	2	2	1.275	5.234
5	1	2	2	1.865	5.698
6	1	2	2	1.583	6.665
7	1	3	3	1.704	5.641
8	1	3	3	1.866	6.144
9	1	3	3	2.280	7.388
10	2	1	2	1.193	5.436
11	2	1	2	1.296	5.965
12	2	1	2	1.444	6.045
13	2	2	3	1.538	6.020
14	2	2	3	1.903	6.408
15	2	2	3	1.715	6.929
16	2	3	1	1.623	5.465
17	2	3	1	2.068	6.245
18	2	3	1	1.879	7.059

3. Results and discussion

The mean values of the temperature change of the bovine bone for each tool are summarized in Table 2.

For each level of the factors, the lower-is better characteristic was calculated by means of Eq. (1).The mean S/N ratios for each level of the process parameters are plotted in Tables 3 and 4, the slope of the lines represents the influence of each parameters and their levels.

As seen in the S/N response graphs (Tables 3 and 4), the highest S/N ratio for minimum drilling temperature were obtained when the coating level 1, drill tip angle level 1 and usage level 1 (coated, 120° drill tip angle and new, respectively). Therefore, the optimal process parameters for the minimum temperature change in the bone are A1B1C1 for drilling with irrigation and A1B1C1 for drilling without irrigation. According to the results there is a significant heat rise in the bone in the experiments which applied without irrigation.

The drills (texture) with 90° tip angle are shown in Fig. 4. The images of the drill tips were taken by means of Hitachi Scanning Electron Microscope 3500N. Fig. 4(a) illustrates the new tool and (b) illustrates the middle used tool which belongs to experimental run 3 (Coated, Angle with 90°, new) (c) illustrates the used tool which use in run 9 (Uncoated, angle with 90°, and 90 times used). As may be seen in the (b), there is not a significant deterioration on the tool form. In Fig. 4(c) the used tool with the uncoated surface shows relatively a worn form. Also this tool produced higher temperatures during the drilling procedure (Table 2).

The analysis of variance (ANOVA) was performed to find the statistical significance of the process parameters effect on the temperature change during the drilling procedure of the bone for a level of significance of 5%. Table 5 shows the results of ANOVA analysis for temperature change in the bone during the drilling with irrigation. Three factors are

Table 3
S/N graph for temperature change in bone during the drilling procedure with irrigation.

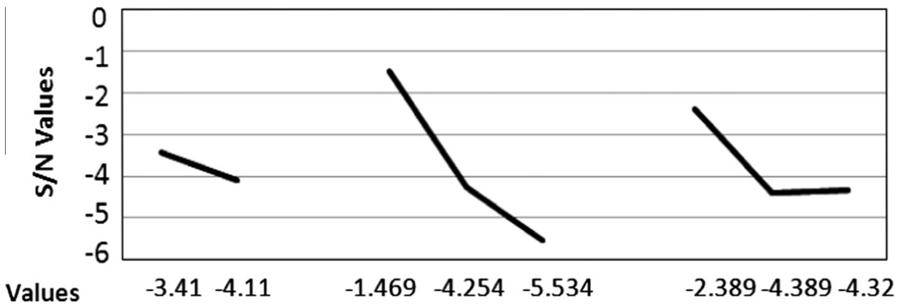
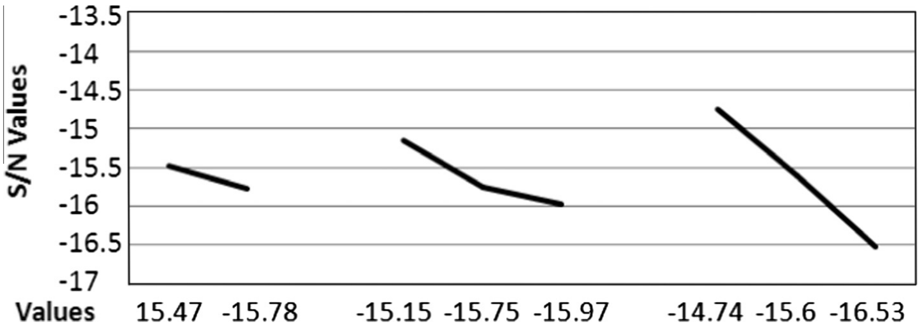


Table 4
S/N graph for temperature change in bone during the drilling procedure without irrigation.



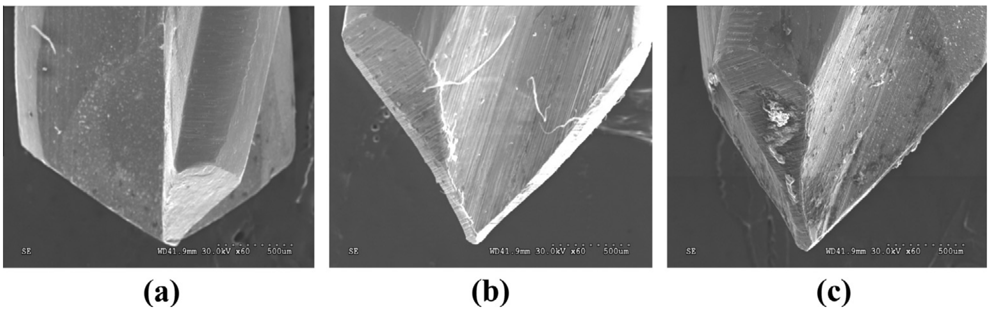


Fig. 4. SEM images of tool; (a) new tool, (b) 45 times used tool and (c) 90 times used tool.

Table 5
ANOVA for temperature change during bone drilling without irrigation.

Source	DF	Seq SS	Adj SS	Adj MS	*F*-test	*P*	$F_{0.05}$
A	1	0.1842	0.1842	0.1842	2.18	0.166	Insignificant
B	2	1.0954	1.0954	0.5477	6.47	0.012	Significant
C	2	4.7830	4.4830	2.3915	28.27	0.00	Significant
Error	12	1.0151	1.0151	0.0846			
Total	17	7.077					
R^2 = 85.66%							

analyzed, as shown in Table 5, coating (A), drill tip angle (B) and the usage condition of tools (C). According to *F*-test, tip angle and usage condition of tool has a statistical and physical significance on the temperature change in the bone during the drilling procedure. Also *p*-values are tested which should be lower than 0.05 for 95% confidence level. Since *p*-value of coating is not less than 0.05, it is also insignificant according to the ANOVA analysis. All of these

Table 6
ANOVA for temperature change during bone drilling with irrigation.

Source	DF	Seq SS	Adj SS	Adj MS	*F*-test	*P*	$F_{0.05}$
A	1	0.0333	0.0333	0.0333	1.38	0.263	Insignificant
B	2	1.4864	1.4864	0.7432	30.66	0.000	Significant
C	2	0.4787	0.4787	0.2393	9.87	0.003	Significant
Error	12	0.2909	0.2909	0.0242			
Total	17	2.2895					
R^2 = 87.29%							

results also similar for the tests which applied with irrigation system (Table 6).

On the basis of the above-mentioned results, this experimental study has obviously indicated that irrigation system, drill tip angle and usage condition strongly affects temperature change in the bone. As seen in Table 2 irrigation system decreased temperature rise.

In literature there are studies evaluating factors that influence thermal change during the drilling procedures have focused on drilling speed, drilling force, drill tool characteristics, irrigation system [29–33]. In order to observe temperature change of bone there are two different methods according to the literature. First method is the infrared thermography. In this method device acquires infrared radiation emitted by bone and transform it into a signal [34]. This technique is easy to use for observing temperature change. However technique is limited in accuracy with an error of up to ±1 °C which is considerable for temperature change. Moreover this technique only detects the surface temperature of the specimens which means temperature results are not belong to the actual drilling site. Second method was applied by means of thermo-couples which is more precise with ±0.50 °C measurement accuracy (TC-08 Thermo-couple Data Logger User Guide). In this experimental study to increase measurement accuracy three thermo-couples embedded for each drilling hole. Repetitive three measurements were applied and mean values of these three points were considered as temperature change of the bone.

The effect of irrigation system for biomedical applications investigated by many researchers and irrigation system was reported as the most effective factor for the procedure temperature [35]. Also in our experiments, according to the precision measurement change of the bone as seen in Table 2, irrigation system has a significant influence on decreasing maximum temperature. Irrigation system decreases temperature with ambient temperature of coolant fluid. Moreover coolant fluid wash away bone chips which is also assumed to decrease drilling temperature and prevents deterioration of the tool [36].

In our experimental study coating type found to be statistically insignificant. The reason for this assumed to be low deterion of the tools as seen in SEM images (Fig. 4b and c). In the SEM investigation of drill tips it was observed that coated tool were in a better condition relatively uncoated ones. Nevertheless, at the end of these experimental study all of the tools were still in a good condition and were able to use as seen in Fig. 4. From this point of view authors claimed further experiments are needed to comment coating affect on the temperature change in the bone during the drilling procedure. However lowest drilling temperature obtained with new tools. Despite of coating type, usage period of the tools found to be statistically significant. This result is parallel with the literature, drilling tools should be used more than 600 times to observe a significant change in the temperature in the drilling area [36].

For experiment three different drill point angles were investigated to observe their effects on temperature. According to the literature larger tip angle produces lower friction during the drilling. Friction directly effects chip removal from implant area, temperature of bone, force, rate of penetration and the geometrically quality of the implant sites [37–39]. The presented experimental result were parallel with literature, 120° worm spiral drills were suggested for lowest temperature.

4. Conclusions

In this experimental study the purpose was to investigate the thermal changes produced by 3 individual drill tip angle, in different usage condition. Three different drilling speed evaluated with and without irrigation and thermal change was monitored. Within the range of selected parameters used in this experimental study, the following conclusions may be drawn:

- In our experimental study it is observed that irrigation system decreased maximum temperature change in the bone.
- The temperature rise for the procedure was obtained from there different points but maximum temperature was observed in the upper thermo-couple related to the friction of bone and mill interface during the drilling (Fig. 2(a) and (b): Schematic draw of bone from (a) Front view).
- Based on statistical analysis of the S/N ratio, the optimal procedure temperature is achieved with coated (level 1) new drills (level 1) with 120° drill tip angle (level 1), (A1B1C1). These results were similar for both irrigation and without irrigation conditions. But the temperature rise was significantly lower with the irrigation system (Table 2).
- Statistical results indicate that the temperature change in the bone was significantly influenced (for the 95% confidence level) by the drill tip angle and usage condition of the drills. The coating is observed as insignificant which conducted they were still in a good condition after the milling procedures.

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