HEAT GENERATION DURING IMPLANT PLACEMENT IN HIGH-DENSITY BONE: EFFECT OF DIFFERENT DRILLING TECHNIQUES (IN VITRO STUDY)

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ABSTRACT

INTRODUCTION: A precise drilling-sequence-protocol is essential for long-term dental implant success in high bone density (mandibular cortical bone of D1-quality). Cone beam computed tomography (CBCT) radiographic imaging and CBCT-based construction of surgical guides have been substantial for diagnosis and treatment planning.

OBJECTIVES: The study aimed to measure the effect of different guided drilling techniques on the amount of heat generated during implant placement in high density.

MATERIALS AND METHODS: Twenty-four osteotomies for implant placement, divided equally into three groups, to test the effect of the three drilling techniques " Undersized Drilling (UD), Undersized Drilling + Ridge Spreader size 4 (UD+RS4) and Undersized Drilling + counter sink size 4 (UD+CS4) techniques". Heat generation was assessed using K-type thermocouple. Drilling and thermocouple canals were guided by the surgical template. Bone assessment, virtual planning of the implants and surgical guide construction were based on radiographic CBCT-imaging and software-based processing. Insertion torque values (ITVs) were recorded from readings of a geared motor.

RESULTS: The thermocouple results showed the least significant difference at 10 mm depth. At 5mm depth, a significant decrease in the temperature difference of the UD+RS4 group and UD+CS4 group compared to UD group was observed. At 1mm depth, there was a significant difference between the UD group and the two other groups.

The UD group showed the maximum peak ITV.

CONCLUSION: the results suggest possible advantages when self-tapping implants are inserted into high density cortical bone of D1-quality by a countersink drill since it provides lesser temperature increase at insertion.

KEYWORDS: CBCT, Drilling techniques, Insertion torque value, Surgical guide, Thermocouple.

RUNNING TITLE: Heat Generation During Implant Placement In High-Density Bone

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INTRODUCTION

Osseointegration is the process and resultant apparent direct connection of an exogenous material's surface and the host bone tissues, without intervening fibrous connective tissue present (1).

Successful osseointegration of dental Implants depends on several criteria, however,

all these parameters are directly or indirectly related to the thermal and possibly to a compressive impact on the bone.(2).

At implant site preparation with surgical drills, excessive heat generation may jeopardies the integrity of the prepared bone by thermal bone-necrosis (3). Heat generations vary with osteotomy location (4). The thermo-conductive rate of the homogenous compact bone is significantly greater than the spongy one which means, the dense bone conduct heat much faster.

The cancellous bone possesses an organic composition, lattice structure, and vascularization that make it an excellent insulator against the frictional heat (4). For these reasons, the cancellous bone is much better than homogenous bone in terms of the thermal decline rate, and the bone regeneration ability (5). Huiskes (1980) (5) proved that the resorption rate of the cortical bone is three times greater than that of the cancellous bone, which reflects the low thermal quality of the cortical bone. Roberts et al. (1987) (6) demonstrated the massive damage of cortical bone around implant resulted from the thermal insult. The higher failure rate of the dental implants in the d1 bone has been attributed to the high temperature the moment the friction between metal surface against bone occurs (7).

Success in implant dentistry depends mainly on osseointegration and maintenance of alveolar bone.

Osseointegration has shown success and high predictability in the literature repeatedly (8,9). Osseointegration of dental implant is not the same as clinical success, because secondary loss of bone fusion may be a recurring problem (10). Another point of concern to achieve success in implant dentistry, is the proper positioning of the dental implants inside the bone. Regarding this study, the surgical guide is a reliable tool for positioning dental implants with a proper angulation. Previous studies have proved a high accuracy for implant surgery with surgical guide, pointing out that a more precise and reproducible implant site preparation could be conducted based on the virtual planning of the implant positions using Cone-beam computed tomography (CBCT), and digital imaging techniques. These tools allowed visualization of the placement of dental implants in three dimensions, which have gained popularity in their applications given their ability to achieve predictable and accurate results (11, 12).

Nevertheless, this issue still critical since multiple ex vivo and in vivo studies warn of significant deviations between virtual planning and in vivo surgical execution using surgical guide (13,14).

This in-vitro study evaluates the outcome of different drilling techniques on the amount of heat generated during implant placement for each surgical technique, particularly in high bone density.

In addition to the measurement of the thermal effect of implant insertion in high bone density, measuring the ITV for each drilling technique is also crucial as an indicator for compressive strains exerted upon homogenous bone (15,16).

The null hypothesis is that the technique of undersized drilling (UD) has no effect on the thermal insult during implant placement in high bone density.

MATERIALS AND METHODS

The research has been conducted after obtaining approval of the Ethics Committee at Faculty of Dentistry, Alexandria University, on April 2018 (23/4/2018)

Sample size

The minimal sample size was calculated based on a study aimed to evaluate the effect of different drilling techniques on primary stability, particularly on poor-quality bone with or without a crestal cortical bone (15,17).A sample size of 8 specimens per group (number of groups = 3) (total sample size = 24 specimens) is the enough required sample for a pilot study, if the aim of pilot study is to demonstrate intervention efficacy in a single group (18).

Selection, Preparation and assessment of the bone specimens

The bovine bone was taken from a cow rib that was near to the vertebral column. The bone type was checked out according to (1) CBCT using the Hounsfield unit. Figure (1, 2) (2) visual inspection of the bone specimen after cutting it (3) drilling impedance (4) implant insertion resistance torque (19,20). In this experiment, the specimens were preserved in saline at 10°C.

Radiographic CBCT analysis and implant planning

The software (primary or a third party) available with CBCT images allowed virtual treatment planning (e.g. implant planning) which was relocated to the surgical site either directly by the image-guided navigation or indirectly via the construction of surgical guides (21-23).

Fabrication of surgical guides

During the treatment planning, the software (DICOM, OnDemand3D, and blue sky), available with CBCT images allowed virtual treatment planning (e.g. implant planning), which transferred to the surgical site indirectly via the construction of surgical guides with 7 cm length, 1.5 cm width and 0.3 cm depth (21-23). Figure (1)

Then, the surgical template was milled using the STL file and Computer Numerical Control (CNC). Figure (2) the template consisted of 20 perforations: four holes were distributed equidistantly along the midline of the template's length for the implant drills; 12 thermocouple perforations that were configured in a constant triple pattern and at a constant distance (0.5 mm) around each osteotomy hole, and the remaining 2 holes are for fixation (24). The diameters of the holes were 4, 1.6, and 3 mm respectively. The insulating material was applied to the exposed surfaces of the thermocouple and its entrance to the bone to separate the environmental temperature from that of the bone (24). Fig (3)

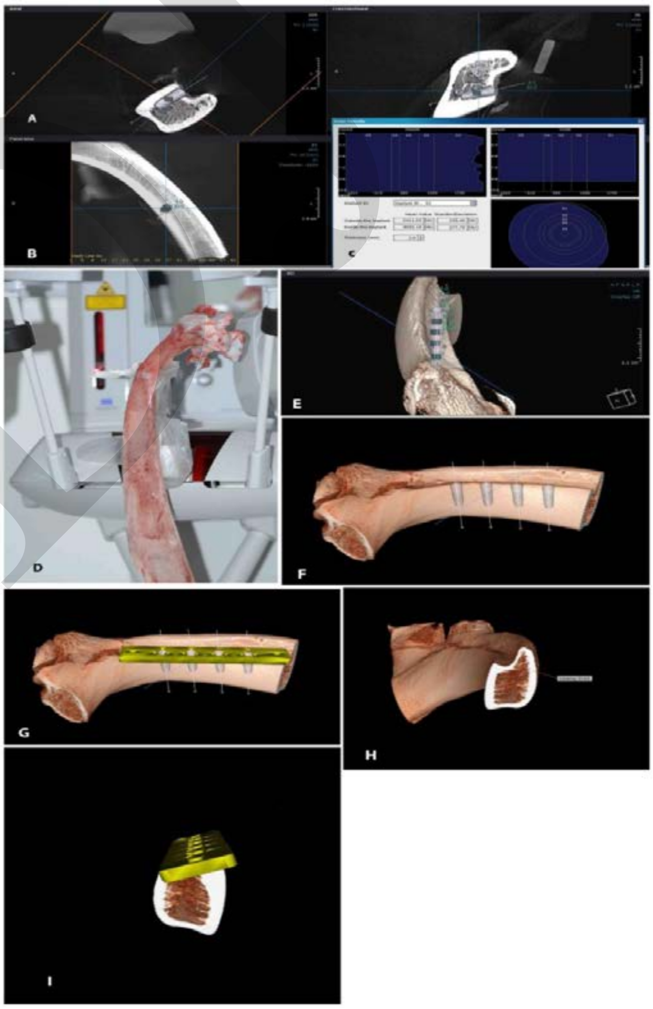

Figure (1): (A,B,C) Checking the bone density around the implant with HU value, D presents the CBCT shooting of the bone sample for assessment, (E, F, G, H, I) presents the virtual treatment planning showing the parallelism of the implants at a certain angle that would be assessed for density, G presents the integration between the surgical template and the bovine bone before sawing the required area for the surgical guide seating, H shows the sawing point, I presents the proposed relation between the guide and the sawed bone.

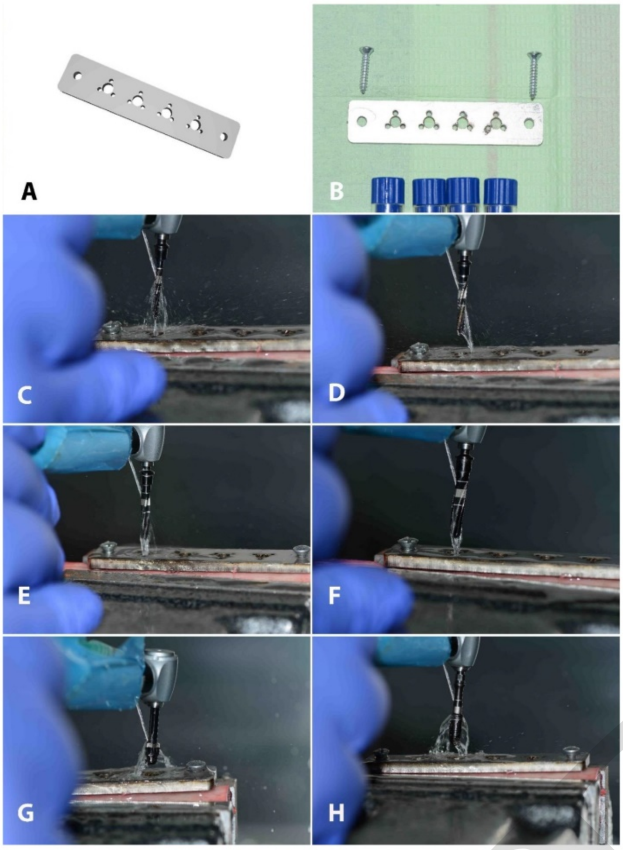

Figure (2): A and B present the STL file of the guide and the Surgical guide after fabrication with two fixing screws, (C,D, E, F, G, H) show the Undersized drilling protocol: A and B demonstrate the initial drills 2.2 mm and 2.6 mm respectively, C and D show final drills 3.4 mm, and 3.8 mm respectively, while E is the cortical drill (countersink) and F is the RS 4 drill (cortical tap drill).

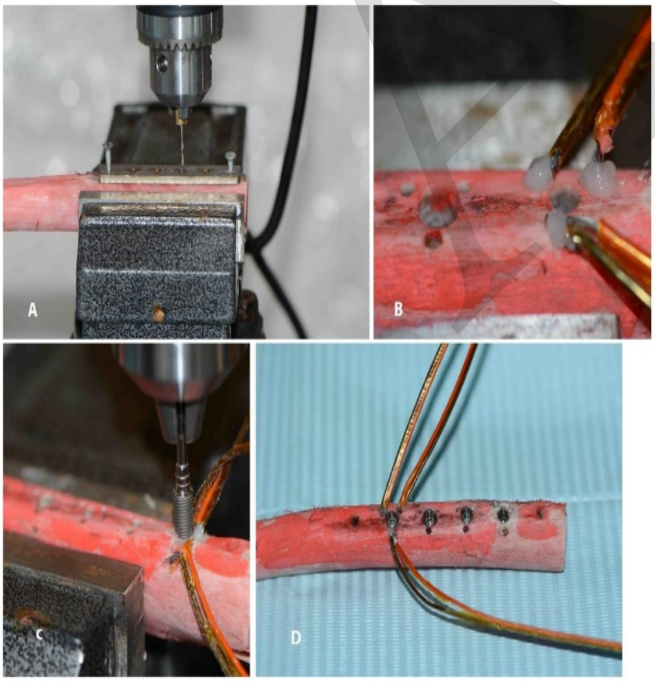

Figure (3): (A) Preparing the thermocouple channels (B) Application of the insulating material, (C, D) show the implant insertion.

Implants selection

24 coronal macro-thread and tapered implants (Dentium, Seoul, South Korea) with diameter 4 mm and length 10 mm that are surface treated with SLA (Sandblasted, large grit, acid-etched implant surface) were used in this study. This design is the most common in the market for the ease of application and good results in terms of osseointegration. It has been evidenced before that the results match the v-shaped thread as the buttress thread design in terms of BIC, thus, osseointegration. Moreover, a previous study proved that the rough-surface screw had slightly more BIC than the machined-surface screw. Steigenga et al. proved that the square thread possessed the highest BIC values. While, the other 2 designs (V-shaped and buttress thread shapes) showed the same BIC percent (25,26). This means that the implants used in this study exert the least amount of friction in favour of hard bone type.

Study design

A total of 24 coronal macro-thread tapered implants (Dentium, Seoul, South Korea) with diameter 4 mm and length 10 mm that is surface treated with SLA were inserted in prepared osteotomies.

The selected twenty-four surgical sites were randomly assigned to the following three groups:

- Group A: eight surgical sites, where the osteotomy was prepared with the Undersized Drilling (UD) technique. (Control group)
- Group B: eight surgical sites, where osteotomy was prepared with Undersized Drilling followed by cortical tapping using ridge spreader drill size 4 (UD+ RS4). (test group)
- Group C: eight surgical sites, where osteotomy was prepared with Undersized Drilling followed by cortical tapping using countersink drill size 4 (UD+CS4).

Application of surgical guide and surgical execution of implant insertion.

After the preparation of the bone specimens, the surgical guide was fixed to the bone sample with the aid of the two screws (27). Figure (2). The surgical guide was visually inspected before drilling procedures. Then, the canals for the thermocouple were made with the aid of the guide, and an initial drill then widened with the final fissure one. Fig (3)

The three different drilling techniques were used with the aid of the surgical template started with the undersized drilling technique. The undersized drilling technique, according to the manufacture (Dentium Co., Korea), was 2.2, 2.6, 3.4, and 3.8 mm respectively. All the drilling procedures were carried out with the implant motor system (Dentium, Korea) at a speed of 1000 rpm. Finally, the implants were inserted after removal of the surgical template.

Data Collection

During implant screwing, the implants were inserted perpendicularly to the model surface with constant speed of 30 rpm. The temperature difference was detected by the aid of the K-type thermocouple (code no. EXTT-K-20; Omega Engineering) at three depth levels for each osteotomy. The thermocouple instruments were directly connected into three channels of the thermocouple Reader (Model SR630, Scientific Instruments GmbH, Germany). ITVs were measured by sensors during implant seating (DC Geared Motor, SG775125000-60K, CHINA) with the direct current of 12 VDC, that was connected to 40A PWM Motor Speed Control Switch Manual (10Vdc to 50Vdc), and was mounted to the bench drill. The ITVs were recorded up to 0.5mm below the subcrestal level onto a PC connected to the customized motor (15,28). After the fixation of the bone sample, the osteotomies were visually inspected and then wetted with saline. Figure (4)

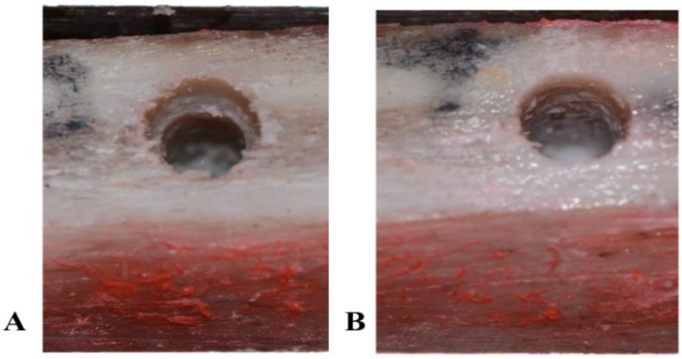

Figure (4): The difference between (A) CD and (B) CT osteotomies (marked D and T respectively).

Data Management and Statistical Analysis
The data was processed and analyzed using Statistical Package for Social Sciences program SPSS (23.0) software (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp). The study included descriptive and analytical data. A P-value of less than 0.05 was considered statistically significant. Mann-Whitney non-parametric tests will be used in this study.

RESULTS

The mean temperature difference was calculated and compared between the groups at three depth levels, revealing a significant difference between the three groups at depths 1, 5 and 10 mm. The thermocouple results showed the least significant difference at 10 mm depth ($p < 0.01$). contrast, no significant difference at depth 10 mm was detected. Figure (5) as for the UD group, the mean temperature difference was 8.30±1.15 oC, 10.85±1.50 oC, and 1.09 ±0.12 oC at a depth of 1, 5 and, 10 mm, respectively.

The mean insertion torque value was 64.13±3.76, 53.75±3.28 and, 46.75±1.39 Ncm for the UD group, UD + RS4 group and, UD + CS4 group, respectively. Table (2) Statistical analysis, comparing UD, UD+RS4 and, UD+CS4 groups, revealed a significant difference between the three groups regarding the peak insertion torque value. The relation between ITV and the cumulative temperature difference concerning the different drilling techniques is presented in Figure (6).

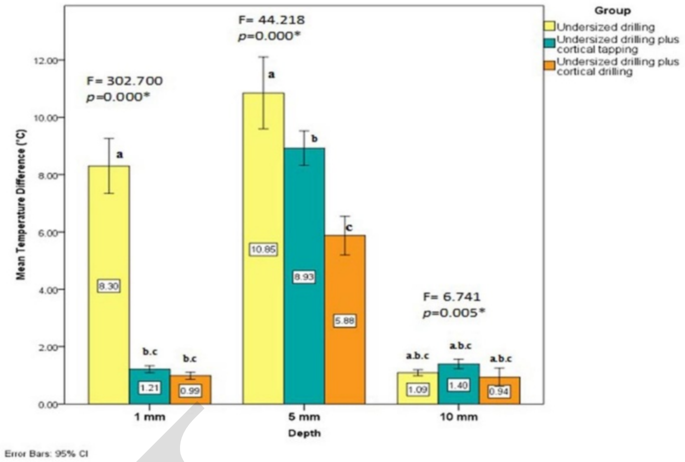

Figure (5): Clustered bar chart with 95% CI of the mean of temperature difference (^{o}C) at different osteotomy depths during implant insertion for different drilling techniques studied.

As for UD+RS4, the mean temperature difference was 1.21±0.15 oC, 8.93±0.72 oC, and 1.40±0.20 oC at a depth of 1, 5 and, 10 mm, respectively. As for the UD+CS4 technique, the mean temperature difference was 0.99±0.16 oC, 5.88±0.81 oC and, 0.94±0.38 oC at a depth of 1, 5 and, 10 mm, respectively. Table (1)

Table (1): The mean of temperature difference (ºC) during fixture insertion for different drilling techniques studied at 1mm depth, 5mm depth, and 10mm depth.

	Group			Test of significance
	Undersized drilling	**Undersized drilling plus cortical tapping**	**Undersized drilling plus cortical drilling**	
Depth = 1 mm Temperature Difference (°C) - n - Min-Max - Mean ± Std. Deviation - 95% CI for mean	8 7.20-10.20 8.30^{a}±1.15 7.3374-9.2626	8 1.00-1.40 $1.21^{b.c}$±0.15 1.0906-1.3344	8 0.80-1.20 $0.99^{b.c}$±0.16 0.8577-1.1173	F= 302.700 *p*=0.000*
Depth = 5 mm Temperature Difference (°C) - n - Min-Max - Mean ± Std. Deviation - 95% CI for mean	8 9.10-14.00 10.85^{a} ±1.50 4.9506-9.3994	8 7.40-9.60 8.93^{b} ±0.72 1.0906-1.3344	8 4.70-7.00 5.88^{c} ±0.81 0.8577-1.1173	F= 44.218 *p*=0.000*
Depth = 10 mm Temperature Difference (°C) - n - Min-Max - Mean ± Std. Deviation - 95% CI for mean	8 1.00-1.30 $1.09^{a.b.c}$ ±0.12 0.98-1.19	8 1.00-1.60 $1.40^{a.b}$±0.20 1.23-1.57	8 0.20-1.30 $0.94^{a.c}$±0.38 0.62-1.25	F= 6.741 *p*=0.005*

n: Number of samples
Min-Max: Minimum – Maximum
CI: Confidence interval
df=degree of freedom
Different superscript letters indicate statistically significant difference
(Adjustment for multiple comparisons using Bonferroni method).
*: Statistically significant ($p<0.05$)
NS: Statistically not significant ($p\geq0.05$)

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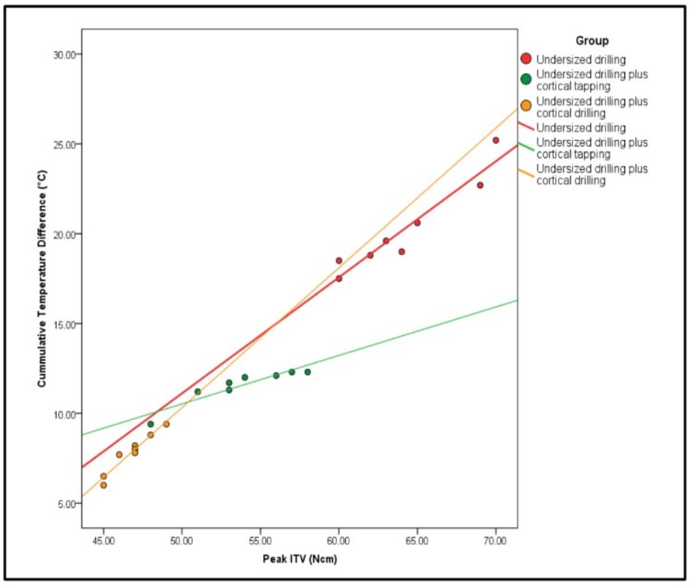

Figure (6): The correlation between ITV and CTD regarding the three drilling techniques.

Table (2): Comparison between the three studied groups according to peak ITV.

	Group			Test of significance
	Undersized drilling	Undersized drilling plus cortical tapping	Undersized drilling plus cortical drilling	
Peak ITV (Ncm)				
- n	8	8	8	F= 68.337
- Min-Max	60.00-70.00	48.00-58.00	45.00-49.00	*p*=0.000*
- Mean ± Std. Deviation	64.13^{a}±3.76	53.75^{b}±3.28	46.75^{c}±1.39	
- 95% CI for mean	60.98-67.27	51.00-56.50	45.59-47.91	

n: Number of samples
Min-Max: Minimum – Maximum
CI: Confidence interval
df=degree of freedom
Different superscript letters indicate statistically significant difference
(Adjustment for multiple comparisons using Bonferroni method).
*: Statistically significant ($p<0.05$)
NS: Statistically not significant ($p\geq0.05$)

DISCUSSION

In the present in vitro study, the authors investigated the relationship between the drilling approach and thermal impact of implant insertion in class 1 bone, which is defined as homogeneous compact bone, and class 2 bone, which is defined as a thick layer of compact bone surrounding a core of dense trabecular bone (29). Implant insertion in the prepared surgical site stimulates heat generation between the surfaces of friction of the implant and bone. The cortical widening and the minimal torque value decrease the stresses over the implant-bone interface reducing frictional impact on the bone cells. This could avoid the critical thermal insult over the prepared bone. The null hypothesis that the technique of undersized drilling (UD) has no effect on the thermal insult during implant placement in high bone density is disproved.

The authors hypothesized that the high-density bone type (D1 and D2) should be prepared differently to avoid exceeding the threshold level of irreversible bone damage by heat-induction without jeopardizing the optimal primary and secondary stability. Therefore, besides the UD technique, the effect of CS4 and RS4 on thermal insult in the high bone density (D1 and D2) was tested, observing their impact upon mechanical stability of implant during insertion. Besides, a correlation between the ITVs and heat generation was defined.

As for Undersized drilling protocol, this scenario is perfect for low-density bone type (5, 8), but as for high bone density, some modifications (like cortical widening) should be considered to reduce amount of friction at the bone-implant interface. This should be taken into consideration to preserve the integrity of the remaining bone, to overcome any heat generation at the bone-implant interface level, which may lead to thermal necrosis worsening the secondary stability of the implant. Moreover, Brånemark et al (30) and O'Sullivan et al (31) suggested the use of a bone tap as the last step before implant placement. The pretapping technique, albeit using a self-tapping implant, prepares the implant thread profile into the recipient bed to allow pressure-free seating. Bashutski et al (32) recommended this pretapping in dense bone to prevent the need to use excessive torque values during implant insertion.

Regarding the bone type, in the year 1972, (33) Matthews & Hirsch recorded similar temperature values while drilling human femoral bone in vivo and in vitro. One of the problems with extrapolation of the temperatures recorded from the animal osseous model on the clinical conditions was mainly attributed to the difference in cortical thickness between the species (34). In the year 2011, Matsuoka et al., (35). simulated the upper jaw and the lower jaw with 1.2 and 2-mm-thick bone specimen respectively to find out the influence of orthodontic mini screw on temperature rise. In the year 2013, Markovic et al. (24). , used bone model of 2 mm compact bone thickness to imitate the upper jaw bone (D3/D4 bone type). In the present study, a 4-6 mm cortical bone thickness was used in a vertical orientation as a model simulating the hardness of the mandibular bone. This orientation was assessed in relation to the surgical template by the aid of the CBCT and the software (DICOM, OnDemand3D, and blue sky) during virtual treatment planning, and proved to be realistic in terms of ITVs.

Many factors stimulate thermal insult during drilling procedures have been discussed in several studies (36). This experiment included not only the thermal impact, but also the compressive state of the implant fixture against the hard bone type. This can define the real threats on the peri-implant bone surface from the thermal insult, which induce thermal necrosis (33,37). This experimental study aimed to facilitate implant seating in hard bone with least possible damage to the surrounding bone.

A comparison of Drilling parameters investigated in the current study revealed the highest median temperature increase of 10.85 ±1.5 oC. The average exposure time was 22 seconds starting from the engagement of the adapter with the implant fixture, until complete seating of the 10 mm implant length against the osteotomy. Besides, the cumulative thermal insult, starting from drilling procedure ending up with implant insertion, could harm the bone inducing osseous necrosis. As for the exposure time of the implant placement (22 sec), this temperature increase (10.85 ±1.5 oC) is not considered a great threat. In literature, a 10°C of temperature rise above the normal body temperature has been recognized as a standard for a clinically expressive outcome that lead to bone necrosis, or even getting worse, an increase of 4.3°C decreasing the quality of “de novo” formed bone (38,39).

With regard to the implant design, multiple studies investigated the temperature rise in relation to the surface characteristics of the dental implants (25, 26). Experimental investigations have demonstrated that the bone response is influenced by the implant surface topography (25). Thread shape and thread details could significantly affect the periimplant stress patterns (26). Threads could affect heat generation during implant insertion because the osteotomy diameter is generally smaller than the diameter of the implant and the coefficient of friction between the threads and the bone might be exceeded. Unfortunately, this research was limited to only one implant macro-design (double-threaded tapered) and only one surface treatment (Sandblasted, large grit, acid-etched implant).

This study had some restrictions. The incapability to measure the temperature difference in the patient’s mouth, and the mismatch of biological materials between dead samples and living bone were the main limitations.

In this experimental study, the ITV proved to be a good indicator not only for the implant primary stability, but also had a statistically significant determination of thermic outcome. This could figure out the drilling technique that maintains seating of the implant fixture with the ideal primary stability. Besides, it guarantees implant seating without over-tightening that leads to cumulative over-heating and over-compression, which in turn, avoids thermal necrosis that could deteriorate the secondary stability of the implant in high calcified bone type. The results of this experiment proved a clue that the ITV of the dental implant is directly proportional to the amount of heat produced. This evidence is harmonious with precedent experimental outcomes by Wikenheiser et al. (1995) (40) that demonstrated direct correlation between the heat generation and torque value during orthopaedic pins seating

The insertion torque value showed significant difference between the three groups with peak values at nearly 4-6 mm depth. However, the UD group showed the maximum peak value in comparison with the other two groups. This exactly explains why the minimal temperature rises recorded with pre-tapping drilling techniques - in contrast to undersized drilling technique - are related to less friction against hard bone type with lower torque during implantation procedure with the same exposure time to frictional forces.

Although that test lacks some clinical identity, the results raise some clinically relevant questions. Do we need to measure the effect of different implant macrodesign features? What about the effect of the implant material on temperature rise? Do we need to assess the accuracy of the surgical guide with post-operative CBCT, to observe the implant planning and the proximity of thermocouple channels to the osteotomies? Is it enough to measure the heat generation during implant placement only, or we have to observe the cumulative thermal insult starting from drilling, ending up with implant insertion? Besides this study, many future studies are needed to answer all those questions. Also, retrospective studies and case reports could help considerably.

CONCLUSION

Both techniques (RS4 and CS4) were beneficial in decreasing the thermal insults upon the bone-implant interface, and therefore decreasing the value of temperature rises during implant insertion in comparison with the UD group. However, the RS4 group exhibiting a relatively higher temperature value at deeper depths with a relatively higher peak insertion torque in comparison with the CS4 group. Within the limitations of this study, the results suggest possible benefits of placement of self-tapping implants in two stage implant surgery with only a moderate insertion torque value into sites prepared by countersink drill (cortical drill) compared to undersized drilling techniques. This exactly happens because cortical drilling ensures more passive fit of the implant fixture against hard bone, compared to the other drilling techniques.

Further studies will have to be undertaken to investigate temperature gradient differences when non-undersized drilling is compared with UD-RS4 and UD-CS4 drilling protocols.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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