Comparative Evaluation of Intraosseous Temperature Change during Osteotomy Preparation without and with the Use of Implant Surgical Guides- An Ex Vivo Study

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Abstract

Introduction. An intimately fitting surgical guide and insertion instrumentation leads to concerns about whether cooling irrigation is able to reach the osteotomy site when using guided surgery; and if it not, overheating the bone becomes a major concern. The use of a surgical stent could be an obstacle to proper irrigation and cooling during implant site preparation.

Aim. The aim of this porcine model study was to evaluate and compare the intraosseous temperature change during osteotomy preparation without and with the use of implant surgical guides.

Methodology. Freshly obtained pig femurs were used in which osteotomy preparation was done, with and without the use of implant surgical guide (experimental groups I and II). A sample size of 30 was calculated at 95% confidence interval. Each group was allotted 15 specimens each. A constant drill load of 2.0 kg was applied at 1000 rpm, maintaining constant external irrigation using normal saline at room temperature. Temperature changes were recorded at a distance of 1 mm from the periphery of the osteotomy site by 2 temperature sensors at depths of 2 mm (point A) and 10 mm (point B).

Results. Using implant surgical guides, the mean temperature change (ΔT) at the depth of 2 mm was 8.19 °C and at the depth of 10 mm was 3.68 °C. And without the use of implant surgical guides, the value at the depth of 2 mm was 4.28 °C and at 10 mm was 0.91 °C. A statistically significant difference was found between using implant surgical guides and not using them.

Conclusions. Surgical guides used for implant osteotomies generated higher bone temperatures compared to osteotomies done without the same, thus, posing to be a barrier for osteotomy site irrigation.

***Keywords*:**Dental implants, implant surgical guide, intra- osseous temperature, implant osteotomy

1. Introduction

Implant dentistry constitutes a highly predictable and successful means of rehabilitation of the stomatognathic system, with success rates between 89% and 95%.[1] The overall success of dental implants depends on the process of osseointegration.

Osseointegration refers to a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant.[2]The high success rate with osseointegration is most importantly related to primary bone healing of the site where implants have been placed.[3] Therefore, adequate preparation of the receptor bed and the presence of healthy bone tissue are critical conditions in the repair process.[4] Adelicate surgical technique is essential to ensure osseointegration. For atraumatic surgical preparation, avoidance of excess heat generation during implant drilling was essential.[5,6] The heat produced is influenced significantly by drill parameters (diameter, material and design of the drill including cutting face, flutes, helices, drill point, number of usages) and drilling parameters (drilling speed, axial load, feeding rate, predrilling, drilling depth, method of cooling, intermittent drilling, sequential drilling etc.)[7]

This concept becomes crucial when the surgical guide is used to drive implant drills. Guided implant positioning provides benefits to both the clinician and the patient: allowing for accuracy in implant placement according to prosthetic needs and in full compliance with anatomical structures; reducing invasiveness and postoperative morbidity while leading to predictable outcomes.[8] However, the presence of a surgical guide could reduce the cooling provided by the irrigation solution, especially in a flapless approach.[9]

Therefore, the purpose of this study was to evaluate and compare intraosseous bone temperature change using drilling technique without and with surgical guides and reporting the difference at the cortical and cancellous bone levels, keeping all other parameters of implant site preparation constant.
Hypothesis: There is a non- significant difference in the intraosseous temperature change at each depth between Groups I and Group II under study.

2. Material And Methods

A parallel type of trial design was used for the experimental study. The study was divided according to the following steps:

Bone Specimen Preparation (Fig. 1-3) - Porcine femoral bone was chosen as the material of choice because of its availability in sufficient quantities, useful size, and its structural resemblance to human bone. They have been used as substitutes for human maxillary and mandibular bones due to their similarity with cortical and cancellous bones and great homogeneity in cortical thickness.[10]

Whole bone specimens from porcine hind quarters were freshly obtained from an already slaughtered animal family of disease-free pigs of age 1-1.5 years, weighing around 50 kg. Portions of mid diaphysis were cut into 30 segments using an electric saw after cleaning and removal of soft tissue, and were marked and tagged. The specimens were stored in a freezer at a temperature of -21 ± 5 ºC in order to maintain their physical properties and prevent dehydration.[11]

Preparation of Temperature Sensor Holes (Fig. 4,5) - LM35 precision centigrade temperature sensors (Texas Instruments)™ were used. The temperature sensor position was planned such that it touches the lateral bony wall of the osteotomy that was closest to the implant bed to be drilled, but was 1 mm away from the implant drill insertion site to avoid damage to the temperature sensors. 2 holes, each 0.8 mm in diameter were drilled to a depth of 8 mm horizontally, for each specimen (Point A and Point B) to house the extremities of the temperature sensors. The hole at point A was drilled at 1.5 mm depth from the surface (cortical bone level) (**P1**) and the hole at point B was drilled at 10 mm depth from the surface (cancellous bone level) (**P2**).

Modification of Implant Surgical Guide - A model surgical guide that housed an 8 mm wide by 6 mm tall navigator metal sleeve/cylinder was used. All the guides were provided with the original resin structure made by the surgical stent manufacturing company (DIO Navi).The supporting structure of these prefabricated guides was trimmed and replaced with a Velcro band for close adaptation on each of the bone specimens.

Modification of The Dental Surveyor - The dental lab surveyor was modified to perform the drilling to prepare the osteotomy in all 30 specimens. The spring of the spring-loaded surveying arm was replaced to a greater gauge spring, such that a constant load of 2 kg could be applied to the implant handpiece (Marathon).

The straight handpiece clamp was modified to accept the implant handpiece. Addition of a custom-made transparent cast acrylic attachment to the survey arm made the clamp to change its orientation such that the handpiece attachment could now be attached horizontally.

Experimental Setup (Fig. 6) - The specimens to be studied were divided based on whether or not an implant surgical drill guide was used during osteotomy preparation. Each group consisted of 15 specimens (A to O).

GROUP I- osteotomy preparation without the use of implant surgical guide.

GROUP II- osteotomy preparation with the use of implant surgical guide.

The study was carried out in a single day in a well-ventilated air-conditioned room, where the temperature was set at 24 ºC. Prior to the drilling procedures and temperature measurements, the bone specimens were thawed for 4 hours to ambient temperature so as to attain the actual conditions of a living bone's biomechanical properties.

The temperature sensors were colour-coded; grey inserted at 1.5 mm depth from the surface (P1), i.e. the cortical bone level, and yellow inserted at 10 mm depth from the surface (P2), i.e. the cancellous bone level. They were secured to the holes and insulated from the outer environment with Teflon tape. A constant axial load of 2 kg was maintained throughout the osteotomy procedure. The surgical drilling unit (W&H DENTALWERK) was set at speed 1000 rpm. Room temperature saline (24 ºC) was used for irrigation. Standard, constant, external irrigation generated by the physio dispenser surgical unit was applied through a standard cannula attached to it and directed to the drill bit at a flow rate of 50 mL/min.

Osteotomy preparation was performed using drills with stoppers (DIO Navi digital navigation implant system), following the recommended intermittent drilling sequence: 2 mm, 2.7 mm. 3.0 mm, 3.2 mm, 3.8 mm, 4.3 mm. Each specimen was drilled 6 times, with the 2 mm drill first, following the drilling sequence and the 4.3 mm drill last. New drills were used for drilling in each group.

Measurement of Change in Temperature - The procedure of drilling the bone specimens was started when the internal temperature of the bone, as measured by the implanted temperature sensors measured 24±2 ºC at cortical level of 1.5 mm depth (P1), and 32±2 ºC at cancellous level of 10 mm depth (P2). These were taken as the baseline temperatures.

The sensors were connected to the Arduino Nano processor board, which in turn was connected via a USB cable to the computer, where the data was recorded in real time on the CoolTerm

Software and the readings were taken every 1 sec. Each specimen was drilled 6 times, giving a total of 12 temperature readings per specimen; 90 drilled sites per group, 180 temperature readings per group; and 360 temperature change registrations were obtained overall.

T1- Temperature of bone during the osteotomy at depth P1.

T2- Temperature of bone during the osteotomy at depth P2.

ΔT1- Change in temperature of bone during the osteotomy from the baseline value at depth P1.

ΔT2- Change in temperature of bone during the osteotomy from the baseline value at depth P2. The Shapiro-Wilk normality test was used to determine if a data set was well modelled by a normal distribution and to compute how likely it was for a random variable to be normally distributed. The independent t-test, also called the unpaired t-test was the inferential statistical test used to determine whether there was a statistically significant difference between the means in two unrelated groups. A P value of 0.05 was considered statistically significant. SPSS (IBM) was used for computation.

3. Results

Table 1 shows the change in intraosseous temperature at the cortical bone level during osteotomy preparation without and with the use of implant surgical guide. The mean temperature change without using surgical drill guide was 4.28 °C, respectively, whereas with using surgical guide the value was 8.19 °C. The change in intraosseous temperature at the cortical bone level, at a depth of 1.5 mm during osteotomy preparation with the use of surgical guide was much higher than without, and this difference was statistically significant ($p=0.000$).

Table 2 shows the change in intraosseous temperature at the cancellous bone level during osteotomy preparation without and with the use of implant surgical guide. The mean temperature change at the depth of 10 mm without using surgical drill guide was 0.91 °C, respectively, whereas with using surgical guide the value was 3.68 °C. The change in intraosseous temperature at the cancellous bone level during osteotomy preparation with the use of surgical guide was higher than without, and this difference was statistically significant ($p=0.000$).

Table 3 shows the overall change in intraosseous temperature without and with the use of implant surgical guides. The mean temperature change within the osteotomy prepared using an implant surgical guide was 5.93 ºC and was higher than the overall temperature change without the guide i.e. 2.59 ºC, and this difference was statistically significant ($p=0.000$).

Graph 1 (Fig. 7) depicts the mean comparative value comparing change in temperature of bone (ΔT1 and ΔT2) from the baseline temperature for each depth (P1 and P2) in Group I and Group II.

Graph 2 (Fig. 8) depicts the comparison of the overall temperature change in Group I and Group II.

4. Discussion

Implant drilling is affected by several factors. These factors affect osseointegration, which in turn affects implant success. Osseointegration is the direct bone contact of the implant body without connective tissue encapsulation at the optical microscopic level.[12] In order to find a link between hampered irrigation in the implant site due to the presence of surgical guide, and osseointegration ultimately affecting implant success, it is primary to understand all the factors affecting osseointegration. For atraumatic surgical preparation, avoidance of excess heat generation during implant drilling was essential. The variety of factors affecting osseointegration are the implant design, topography of implant surface, material and form of implant, host bone bed and its healing potential, loading conditions, primary & secondary stability, adjuvant treatments, medicinal agents and heat generation during osteotomy.[13]Watanbe F et al[14] stated that heat generation during implant site preparation was one of the important factors influencing osseointegration.

Of all the literature available to us on implant drilling and its factors, the one factor which was least studied was the use of surgical guides and their effect on internal bone temperature. Guided implant surgery may seem to provide dental professionals with a holistic, reliable and precise solution to sophisticated cases bringing about new and exciting possibilities. However, owing to the presence of an intimately fitting surgical guide and insertion instrumentation, concerns aroused about whether cooling irrigation was able to reach the osteotomy site when using guided surgery; and if it not, overheating the bone becomes a major concern.

As a part of standardization of the procedure, all parameters affecting heat generation within the osteotomy were kept constant except for the parameter under study.

This study was carried out in non-vital porcine femoral bone samples. Mosekilde et al[10] have stated that pig bones are suitable proxies for human remains due to similarities in structure and growth and due to their similarity with cortical and cancellous bones and for their great homogeneity in cortical thickness. To retain the mechanical and thermophysical properties, and to prevent dehydration, the bone samples were stripped and frozen in the refrigerator as suggested by Lundskog.[11] Temperature sensor was one of the direct methods based on heat sensitive probe connected to thermometers or computer software. In this study, a basic LM35 temperature sensor was used.LM35 sensors were utilised in this project. The ease of availability, low cost, easy usage, low-output impedance, linear output, low margin of error, non-requirement for a power source, and precise inherent calibration made interfacing to readout or control circuitry especially easy; thereby making it the choice of sensor to be used.In order to keep all drilling parameters constant, the speed of the surgical drilling unit was set at 1000 rpm, and a constant force of 2 kg was maintained. Abouzgia and his colleagues[15-17] recommended that high speed drilling with a large load might be desirable due to decreased bone temperature.Tehemar[5] noted that low hand pressure that usually falls in the range of 2 kg should be applied throughout the complete bony housing preparation to generate less heat. External irrigation with room temperature saline was used. Sener et al[18] demonstrated that external irrigation at room temperature can provide sufficient cooling during drilling, and that saline used at lower temperature was more effective to prevent heating of bone. The use of a graduated series of drills used to widen the site as has been recommended by the Scandinavian osseointegration group, [3,19,20] where new drills were used in each group. The cutting surface of trephine bur drills can be damaged by as few as 12-18 drilling procedures.[21]

Several studies have demonstrated that heating bone to 47°C for 1 minute reduced the amount of bone that grew into the implant and compromises its regeneration.[21,22]

During implant site preparation, the threshold level for bone survival has been established at 47°C, keeping the drilling time below 1 minute.[23]

Guided surgery for dental implants has become the gold standard for dental implant therapy. It is a helpful tool for the diagnosis, planning, and treatment of patients with no teeth or partial dentition. In guided surgery, an individualized surgical drill guide is created using a stereolithographic model based on computed tomography. The results of our study indicated a greater change in temperature, i.e., higher heat generation at depths 1.5 mm and 10 mm during osteotomy preparation through guided surgical approach compared to conventional drilling. There was a greater rise in temperature with the use of a surgical guide when drilling, regardless of the depth of drilling and the diameter of the drill. These results were statistically significant for both cortical and cancellous bone levels for both the groups ($p= 0.000$). None of the techniques exceeded temperature values critical for bone necrosis which is 47 ºC. These values were in line with data reported in several in vitro studies conducted by Misir et al,[24]Migliorati et al,[25] dos Santos et al,[26]Bulloch et al,[27] utilizing various bone models and methods of temperature measurement. This difference was theorised because metal sleeves used in the drill guides do not allow irrigation solution to reach the preparation sites during drilling. The effect of drill guide usage, thus was very significant at the cortical level of the prepared bone site. This level of the site was susceptible to higher warming than deeper parts due to prolonged exposure to friction forces and higher coefficient of friction of cortical bone layer. Without he use of drill guide, the irrigation solution was routed directly to the drill tip, penetrating the underlying tissues, thus providing control of heat generation. Metal sleeves in the guided approach, limit direct irrigation contributing to a tremendous increase in the adjacent bone temperature. This temperature increase could occur due to the heat conducted to the superficial layer of bone via the friction of the metallic components of drill guide.

The temperatures measured during drilling with surgical guides were below 47 °C. Hence, the presented results does not discourage the use of surgical guides, and denote that attention to the drilling procedures with abundant irrigation can compensate for this expected heating of bone.

Heat generation in the bone, associated with the guided surgical approach demands the need for an effective method of heat control. Internal irrigation may be of advantage in guided surgery, but its efficiency could be impeded due to clogged irrigation points when dense cortical bone is involved. Higher jaw bone temperatures have been documented *in vitro* when guided implant site drilling was performed with combined irrigation compared to external irrigation only.[9] Irrigation at room temperature, through the drill guide with a flow rate of 50 mL/min or more could avert overheating of the bony walls at the implant site.[21] Regarding obstruction of irrigation flow by metal sleeves in guided surgery, it has been recommended to modify the drill guide to allow easier access of irrigation solution at the site of cortex penetration.[28] It has been reported that by applying intermittent load and performing sequential drilling, the mean temperature recorded decreases, regardless of the pressure applied by allowing the escape of bone chips and access for the irrigation solution. Boa et al[29,30] advocated the use of chilled saline at 5 ºC during implant site drilling via the guided approach is advantageous due to adequate control of adjacent bone temperature.

Limitations. There are significant differences between dead and living bone regarding actual density and cellularity, water rate, fluid movement and thermal conductivity. These variables may explain the bone viability even if temperatures above threshold levels have been reached. Further studies need to be conducted in an in vivo setting to elucidate the effect of surgical guides on temperature change during osteotomy preparation and confirm these preliminary results.

Conclusion

Within the limitations of the study, it was concluded that:

The mean change in intraosseous temperature during osteotomy preparation without & with implant surgical guide at the cortical level was significantly higher than that at the cancellous level.

The change in intraosseous temperature at the cortical & cancellous bone level was much higher with the use of implant surgical guide, and this difference was statistically significant.

The overall change in intraosseous temperature within the osteotomy prepared using an implant surgical guide was higher than the overall temperature change without the guide, and this difference was statistically significant.

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TABLES

TABLE 1

	Group	Mean	Std. Deviation	Mean Difference	t	*P* value
ΔT1	Group I	4.2753	0.17138	-3.919333	-65.428	.000
	Group II	8.1947	0.15638			

TABLE 2

	Group	Mean	Std. Deviation	Mean Difference	t	*P* value
ΔT2	Group I	.9060	0.16591	-2.77000	-27.230	.000
	Group II	3.6760	0.35735			

TABLE 3

	Group	Mean	Std. Deviation	Std. Error Mean	Mean Difference	t	*P* value
Overall Temperature Change	Group I	2.5907	1.72146	.31429	-3.34467	-6.352	.000
	Group II	5.9353	2.31388	.42246			

LEGENDS

Fig. 1. Schematic diagram showing the cross-section of the bone specimens

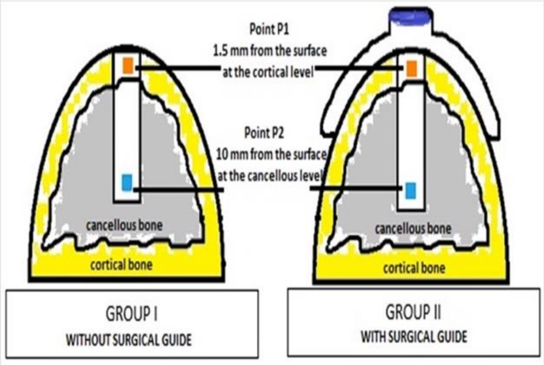

Fig. 2. Schematic diagram showing the cross-section of the bone specimen with the temperature sensor positioning

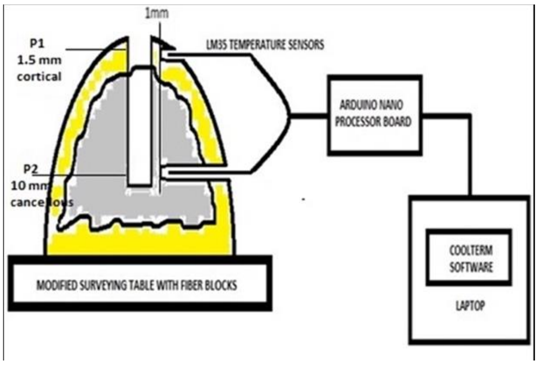

Fig. 3. Bone specimens in Group I and Group II- without and with surgical guide

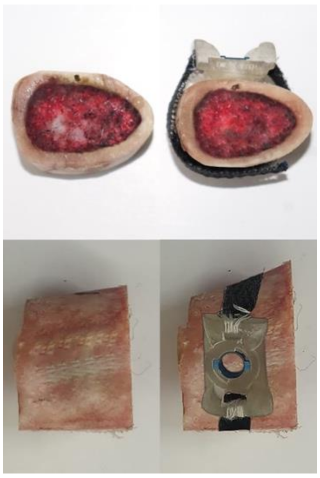

Fig. 4 Arduino Nano processor board and the temperature sensors attached to it

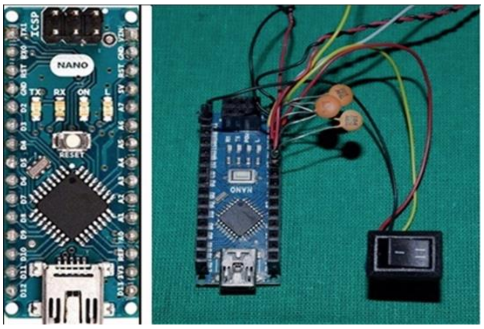

Fig. 5 Insertion of the temperature sensor probes

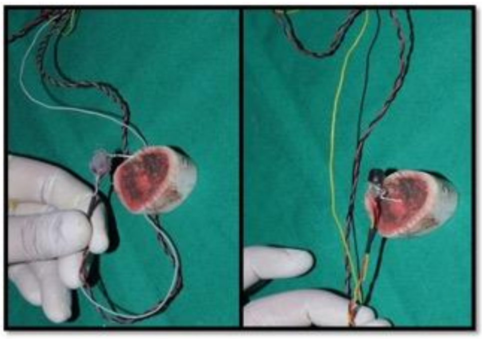

Fig. 6. Experimental setup

Fig. 7. Graph depicting the mean comparative value comparing change in temperature of bone (ΔT1 and ΔT2) from the baseline temperature for each depth (P1 and P2) in Group I and Group II

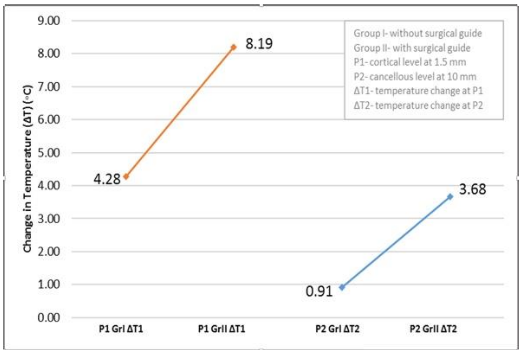

Fig. 8. Graph depicting the comparison of the overall temperature change in Group I and Group II