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Investigation of Thermal Changes in Dental Soft Tissue under 810 nm Low Level Diode Laser Radiation in Osseointegration

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Abstract

Today use of lasers in Implantology has made significant progress, so that requires far less traditional methods of treatment and it has been increased speed of healing. One of the lasers applications in implantology is in the process of osseointegration which made minimum the prolonged time among of planted surgical implants, prosthesis fabrication and implant. Aim of the present survey is to examine and record the temperature changes caused by low level diode laser (Mark GIGA) around 810nm wavelength during laser interaction with tissue. Besides in a clinical study, the surface temperature changes of soft tissue recorded by IR Thermometer once before and after the diode laser radiation at 10 implants placed on 4 patients (3 women and 1 man) in 15 points (total 48 points) from different parts of tissue. Then, the temperature data analyzed by COMSOL Multiphysics 5.2 software. However, the soft tissues temperature changes under diode laser treatment of osseointegration but don't damage tissues. Also after inserting implants, the laser irradiation cause more stability and reduce the duration of treatment.

Keywords: Implant; IR Thermometer; Low level laser diode; Osseointegration; Temperature changes

Introduction

Despite that today implants are widely used and the remain rate also is high in the mouth [1], significant improvement in the treatment of peri-implantitis also occurs with the addition of diode laser therapy [2]. Osseointegration or Osteointegration refers to a direct bone- to-metal interface without interposition of non-bone tissue [3]. The 810 nm laser diode at different impulse regiments leads to apical coagulation that reduces the risk of possible complications to emerge [4-6].

When the light from dental lasers is absorbed, it is converted to heat [7] and beside the apical coagulation the hard dental tissues can be damaged [8]. The thermal effects [9] of this heat depend, in large part, on tissue composition (that is, the amount of water and organic and inorganic components in the tissue) and time interval that the beam is focused on the target tissue [7]. Overheating of the dentinal walls and per apical tissues can lead to irreversible Changes [5]. The duration of exposure results effect on increasing temperature that may cause the tissue changes in structure and composition. These changes may range from denaturation to vaporization and carbonization, and even melting followed by recrystallization in the case of hard tissue [7,10,11].

Heat transfer during dental treatment and routines can indicate range of changes in temperatures between -5 to 76/3°C [12]. Periodontal tissues are not damaged if the temperature increase is kept below 5°C. A threshold temperature increase of 7°C is commonly considered as the highest thermal change, which is biologically acceptable to avoid periodontal damage [13,14]. Change of temperature on the outer root surface and apex with 7-8°C does not lead to periodontal damage but temperature rise more than 10°C can damage the surrounding bony structures [15,16].

The use of 810 nm high-level diode laser change the surface properties of implants which is reason treatment during of peri implantitis should be carefully applied [17]. However, the diode laser with a wavelength of 810 nm has a suitable coagulation properties similar to Nd: YAG laser [18,19] and its feature is tissue surface adsorption with penetrate into the underlying tissues [20,21].

Then, for detecting the temperature changes need to thermometer devices. The IR thermometers are fast becoming a staple item in health care operations and have revolutionized routine care procedures by eliminating or dramatically reducing the lag time associated with temperature determination in diagnosis [22]. The purpose of this study is record and simulation of thermal changes on peri-implant tissues that occur in osseointegration treatment during laser radiation and tissue interaction before prosthesis fabrication and their loading.

Experimental Method

A clinical study has been done based 10 implants placed on 4 patients (3 women and 1 man) in 15 points (total 48 points) from different parts of gingival tissue. The surface temperature changes of peri-implant tissues are measured and recorded by IR thermometer at thermally controlled environment without heating or cooling sources at air conditioned room temperature 23°C, before and once immediately after diode laser radiation. The 810 nm "GIGA LASER" system by an optical fiber with 400μm diameter used in experimental process (Figure 1).

Laser therapy done in continuous mode by 200mW radiation power and temperature distribution within 40 seconds that gives equivalent 8J energy in tissues. Also, the surface temperature of pri-implant tissues measured by infrared thermometer at the beginning and end of the laser radiation process, then to study and evaluate the heat transfer and temperature distribution in tissues, due to applying a thermal light sources such as diode laser, the recorded temperatures have been simulated and processed with COMSOL Multiphysics 5.2 software 9 (Figure 2).

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Figure 1: Laser unit "GIGAA LASER".

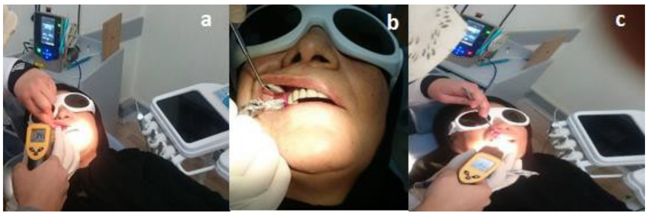

Figure 2: Design of the investigation – Before(a), During(b) and after(c) laser treatment.

The temperature distribution in biological tissue can be predicted from the Pennes equation [23]:

$$\rho C_t \frac{\partial T}{\partial t} = K_t \nabla^2 T - W_b C_b (T - T_b) + Q_m + Q_v \tag{1}$$

Where ρ, C_t, K_t are the density, specific heat capacity, and thermal conductivity of the tissue respectively. T is the temperature of the biological tissue, T_b is the temperature of blood, Q_m and Q_v are the rate of heat generation per unit volume due to the metabolism and external heat source, respectively. Also, W_b and C_b are perfusion rate and specific heat capacity for blood, respectively.

In COMSOL Multiphysics 5.2 software, the model to describe the heat conduction is as follows:

$$\delta_{ts} \rho C_t \frac{\partial T}{\partial t} = \nabla.(-K_t \nabla T) - C_b W_b (T_b - T) + Q_m + Q_v \tag{2}$$

where δ_{ts} the coefficient of time scale. Before the heating, the metabolism and the initial temperature of tissue (T0) and blood (Tb) are related by T_0-T_b=Q_m/$W_b C_b$ equation. If we set δ_{ts}=1, equation (2) is corresponding to eqn. (1), then we can use COMSOL Multiphysics 5.2 software to solve the Pennes equation.

Similar to above, the TWMBT (thermal wave model of bio heat transfer) equation in biological tissues can be expressed as [24]:

$$\nabla.\,(K_t \nabla T(x,t)) + W_b C_b (T_b \text{-} T) + Q_v \tag{3}$$

$$+\tau\left(-W_b C_b \frac{\partial T}{\partial t} + \frac{\partial Q_m}{\partial t} + \frac{\partial Q_v}{\partial t}\right)$$

$$= \rho C(\tau \frac{\partial^2 T(x,t)}{\partial t^2} + \frac{\partial T(x,t)}{\partial t^2}$$

To simplify the problem, the Q_m, K_t, W_b, τ, ρ, and C are assumed to be constant

Considering that the heat source does not change with time, eqn. (3) can be rewritten as follows:

$$\rho C\tau \frac{\partial^2 t}{\partial t^2} + (\rho C + W_b C_b \tau) \frac{\partial T}{\partial t} + \nabla.(- = W_b C_b (T_b - T) + Q_m + Q_v \tag{4}$$

In COMSOL Multiphysics 5.2, the model of partial differential equation is as follows:

$$e_a \frac{\partial^2 T}{\partial t^2} + d_a \frac{\partial T}{\partial t} + \nabla.\Gamma = F$$

If we set, Γ=-$k_t \nabla T$, F=-$W_b C_b (T_b$-T)+Q_m+Q_v e_a=$\rho C\tau$ and d_a=ρ+$W_b C_b \tau$ the model can describe the TWMBT equation, which can be solved by the software of COMSOL Multiphysics 5.2 [25].

After determining the geometry and special material, the intended tissues modelling in two-dimensional space by physical state of Bioheat-Transfer in Biological-Tissue sub model (that is activated in all borders) and time dependent study mode (that is used when field variables change over time). Then, the respective temperatures with determining the initial temperature are given based on different parts of the simulated tissue which has the physical and thermal parameters in Table 1. The results in both TEMPERATURE and CONTOURS ISOTHERMAL at zero and 40 seconds are calculated. (Due to the absence of the gingival tissue in COMSOL software, we used the skin tissue for simulation since is similar to gingival tissue without corneum cells).

The light-heat source is placed on surfaces, for making the simulated conditions near to the real conditions. By simulating of these points in every time, the temperature analysis in different depths of tissue can be acquired and observed the continuously thermal extension in tissue and the method of heat transfer.

Finally, by using the measured temperatures with infrared thermometer, we processed and simulate the recorded temperatures under COMSOL Multiphysics 5.2 software. In this survey, we performed the treatment processes on a female patient for 5 points of the 5 placed implants as follows (Figure 3 and Table 2).

Property	Name	Value	Unit
Heat capacity at constant press…	Cp	3391[J/(k..	J/kg.k)
Density	Rho	1109(kg/	kg/m³
Thermal conductivity	k	0.37[W/(	W/(m.k)
frequency factor	A	4.58E+72	1/s
Activation energy	dE	4.71E+05	J/mol

Table 1: Physical and thermal parameters of skin tissue in COMSOL Multiphysics 5.2.

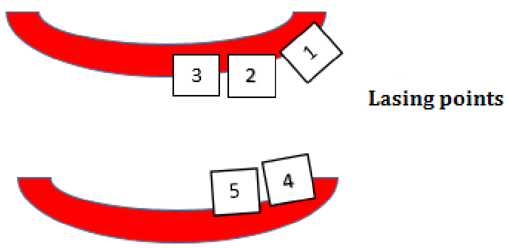

Figure 3: Schematic diagram of maxilla and mandible lasing point.

Temperature (°C)	Point 1	Point 2	Point 3	Point 4	Point 5
Before lasing at time ziro	34.2	34.7	34.9	34.6	34.9
Immediately after 40(s) lasing	35.4	6.5	35.5	6.0	35.4

Table 2: Measured temperature(°C of peri-implant tissues before and Immediately after lasingat times zero and 40 seconds.

Results

In COMSOL software, the obtained temperatures from the tissue points simulated at zero and 40 seconds in both TEMPERATURE and CONTOURS ISOTHERMAL which can be observed in Figures 4-8. As we shown, the heat developments are clear due to the thermal column and its color alongside the figures proposed the temperature rates.

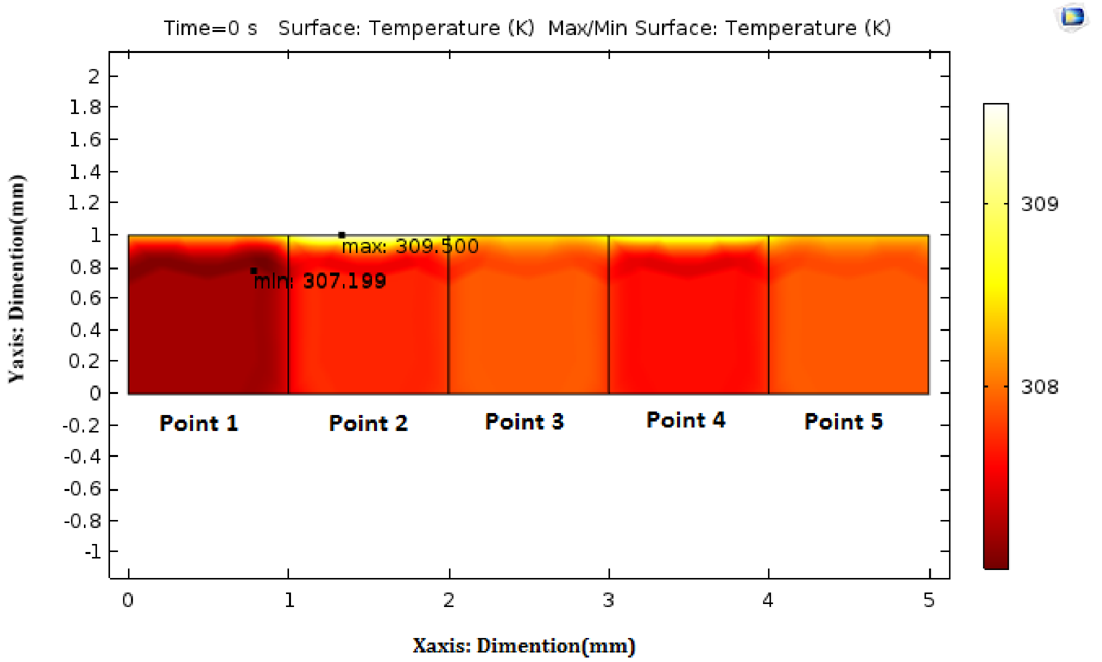

Figure 4: Simulation of temperature (⁰k) distribution at 5 points from tissue surfaces at time zero.

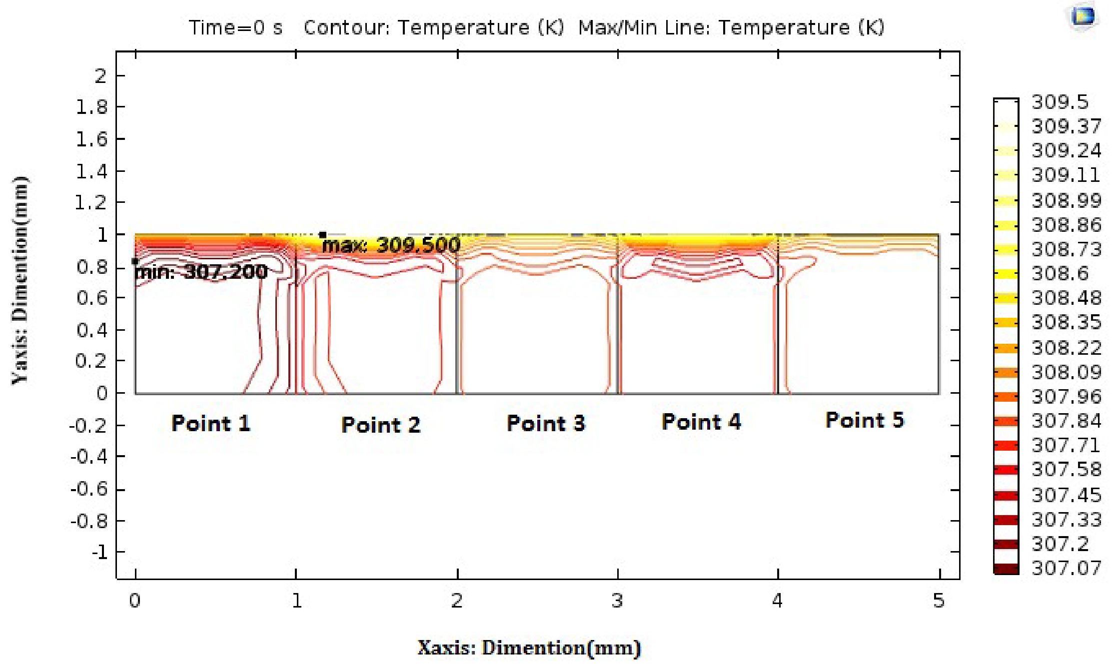

Figure 5: Simulation of contours isothermal temperature (⁰k) from tissue surfaces at time zero.

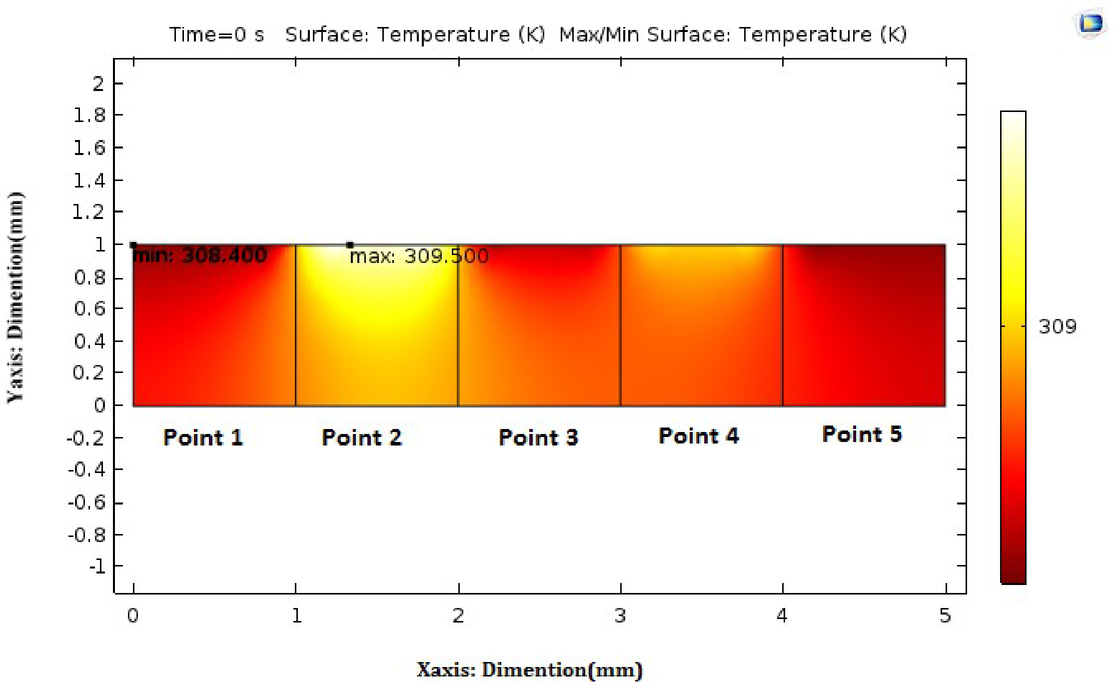

Figure 6: Simulation of temperature (⁰k) distribution at 5 points from tissue surfaces after 40 seconds.

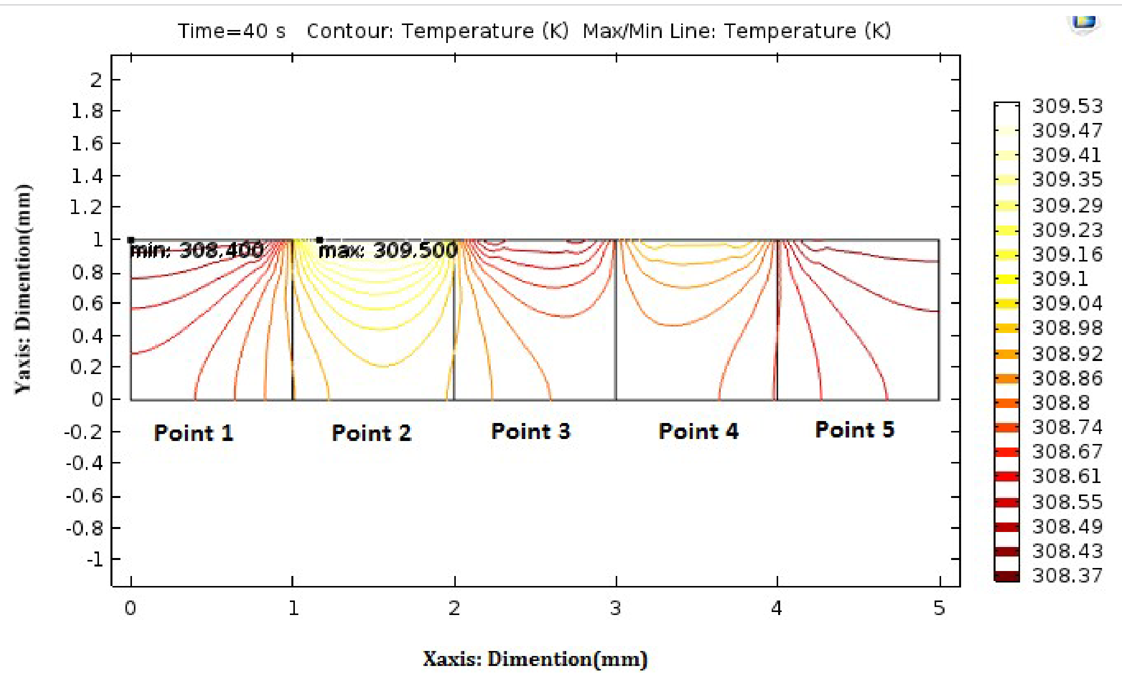

Figure 7: Simulation of contours isothermal temperature (⁰k) distribution at 5 points from tissue surfaces after 40 seconds.

Figure 4 shows the tissue surface initial temperature before the interaction with laser at zero time. According to this figure and compare the color of each region with the next thermal column, we observed the thermal interval and extent of threshold damage (308 and 309°K, are 35 and 36°C, respectively). Also, the maximum and minimum temperature levels that marked in Figure 4 proposed 309.500 and 307.199 K (equivalent to 36.5 and 34.199°C), respectively. Since, the temperature changes at base time is less than 5°C (2.301°C), therefore it has not any damage effect. The characterized numbers in X axis and Y axis determinant the partition dimensions (1mm) of simulated lasing tissues that each part use to show one point. For easier comparison of points, we put them besides in one figure.

As shown in Figure 5, the tissue surface has been displayed before the interaction with laser at zero moment but in contours mode. By

Session	Point 1	Point 2	Point 3	Point 4	Point 5
Stage 1	-0.6	-0.6	0	-0.5	2.4
Stage 2	2	2.4	2	0.3	0.6
Stage 3	1.2	1.8	0.6	1.4	0.5
Stage 4	0.4	-0.2	-0.2	-0.8	-0.1

Table 3: The thermal changes (°C) instead of time(s) in all Sesstion.

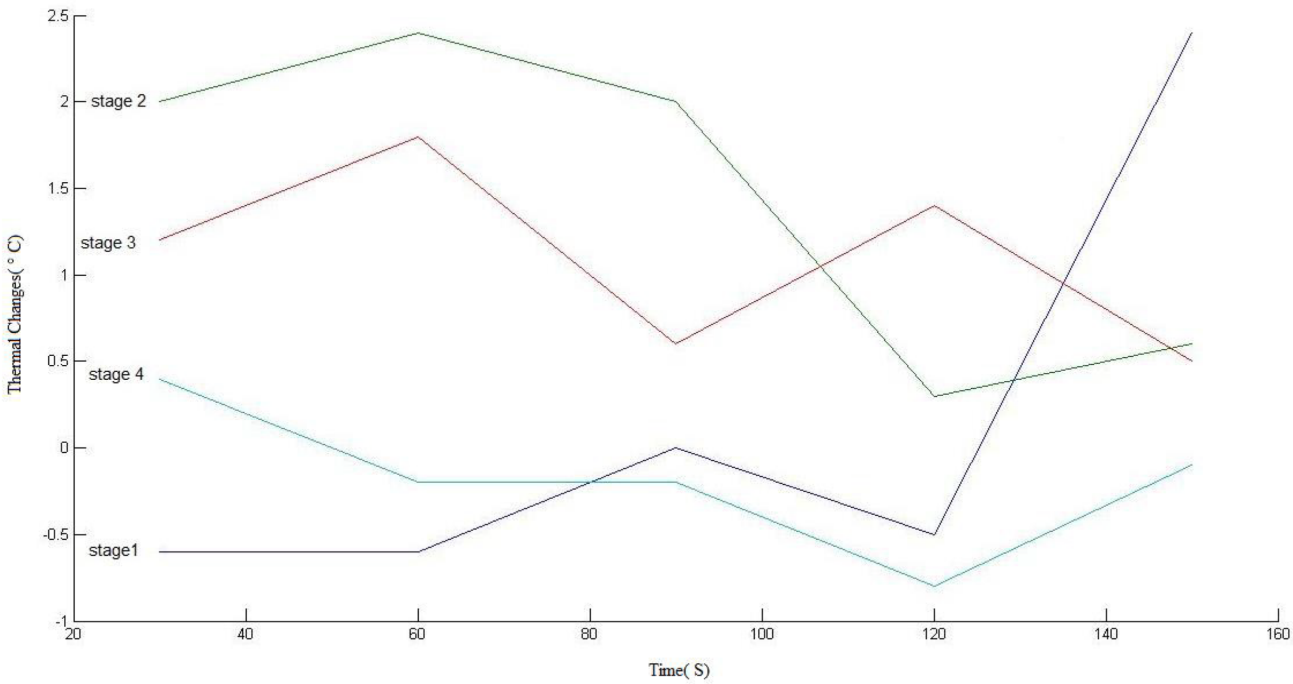

Figure 8: The thermal changes (°C) instead of time(s).

comparing the color of each region from the next thermal column, it determines that the temperature distribution more precisely at a spacing. Similar to the previous results, the initial temperature for the tissue is safe and also has been specified by maximum and minimum contours lines.

Figure 6 shows the tissue reaction immediately after laser interaction and within 40 seconds using of light-heat source to the tissue surface. By comparing the thermal column that embedded besides the Figure 6 and considering the maximum and minimum temperature points, the thermal diffusion in depth of tissue is not visible more than 309.500°K or 36.5°C. Regard to rising temperatures below 5°C, the safety of intended light-heat source with mentioned power on tissue surface have shown in the simulations, too.

Figure 7 also propose the tissue immediately after interaction with the laser source and within 40 seconds applying laser to the surface of tissue in contours mode. By comparing the embedded temperature column near to the profile, the minimum and maximum points, penetration of counters drawn lines and the heat penetration into depth of tissue are not more than 309.500°K, so it does not make damage to the tissue.

After simulation and investigation of all the temperature's samples, for a closer view and comparing with threshold (7°C), we proposed a form of temperature changes diagrams (°C) instead of time(s) in same samples, but in all therapy sessions (Table 3).

Finally, Figure 8 shows patient's thermal changes in all laser therapy sessions; due to process line at the first session temperature changes that shows the range of a $-0.6 \le T \le 2.4$ at time interval of $0 \le t \le 40$. In the same period of time, other sessions thermal changes are in range of $0.3 \le T \le 2.4$, $0.5 \le T \le 1.8$ and $-0.8 \le T \le 0.4$, respectively. As shown in Figure 8, the maximum and the minimum changes are about 2.4°C and 0.6°C, respectively. So, the temperature changes are less than 5°C above the thermal threshold (7°C). However, these temperature changes are safe for dental tissues under lasing.

Conclusion

In this research, the registered temperature changes in osseointegration laser therapy based on 10 implants placed on 4 patients (3 women and 1 man) in 15 points (total 48 points) from different parts of tissue investigated. According to the simulation results, the laser therapy of osseointegration with temperature changes between -1.6 to 2.4°C temperature accompanied, it means that the amplitude changes is less than 3°C. Since, these 5°C and the threshold limit (7°C). By this information under the shallow and superficial penetration, the laser heat is safety for oral and dental tissues ($T \le 5, T_{threshold} = 7$).

As a result, the soft tissue temperature changes due to low level 810 nm diode laser are biocompatible and don't any damage effect on tissues. Also, after inserting implants by studying on the patients, we observed that laser irradiation cause more stability and reduce the duration of treatment.

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