An experimental investigation about the heat transfer phenomenon in human teeth

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Abstract: *This paper illustrates an experimental investigation about heat transfer phenomenon in human teeth. Common polymerization light sources are used as the main heat source; Micro-Thermocouples of type K are utilized to sense the temperature of tooth and environment; because of the high accuracy of the thermocouples, measurements are trusty and very close to the real condition. The data is acquired via a serial communication between a portable PC (laptop) and the visualization system. The experimental data are used to calculate the effective overall thermal diffusivity of tooth and therefore can be exploited to investigate the possible damage in tooth during light polymerization process.*

Keywords: Heat transfer, micro-thermocouple, dental pulp, human tooth, light polymerization.

1. Introduction

In modern dentistry, as in whole medicine, heat effects and heat transfer phenomena are of great importance. Heat transfer occurs in both daily life and curing process. The thermal environment of teeth during daily life varies over a wide range of temperatures (−5 to 76.3 ◦C) (table1) [1, 2]. This wide temperature range is so perilous and can create irrecoverable injuries in teeth tissue. With the rapid growth of dental instruments, high-energy laser lights [3-5] and polymerizing units [6, 7] are increasingly employed in dental surgeries for applications such as bleaching, polymerization of dental restorative materials and hypersensitivity treatments. Table_2 lists currently available treatments and corresponding intrapulpal temperature rise (IPTR). considerable changes in temperature as a result of utilizing these instruments occur during treatment procedure and may cause injury to tooth hard (enamel and dentine) [1, 8–10] and soft components (dental pulp) [11–13], figure1 shows the details of tooth layers. The thermo-physical properties of tooth

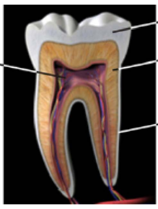


Fig. 1: A cut-away image of human tooth illustrating composite layers

vary from one layer to another; they even differ from an immature person to a mature person in the same layer [14, 15]. The mismatch in the thermal expansion coefficients between tooth hard components (enamel and dentine layers) may induce thermal pressure, followed by split inception and propagation through the dentine-enamel junction (DEJ) [16, 17]. Furthermore, when the temperature in the pulp chamber exceeds the critical value (e.g., ~42.5°C), the pulpal damage occurs [12, 18]. Uhla et al. [19] found that using a high power halogen LCU for a short time or a standard halogen or LED LCU for a longer time did not result in a considerable difference in the temperature increase or the number of living cells within a pulp chamber (figure1). However, Zack and Cohen [20] found experimentally that the healthy pulps of monkey tooth were unsuccessful in recovering in ~60% of the cases if the intrapulpal temperature increases to 46.5°C and ~15% failed to recover when heated to 42.5°C, with pulp necrosis (total irreversible damage) observed the temperature acquires 52°C. Despite the wide applications of these high-tech dental treatments, the base of their mechanisms are far from clear. Besides, the degree of tooth damage depends on a wide range of reasons, most significant of which are individual specifications (e.g. age, sex and race). The swift usage of polymerization lights has brought measuring temperature in tooth layers to a higher level. In addition, there is an essential need to investigate the heat transfer phenomenon in human teeth. Meanwhile these investigations and measurements provide helpful tools for prediction of possible damage for applications of light sources during polymerization procedures. The aim of this research is to investigate the temperature rise in human tooth (in vivo) because of utilizing light sources common for polymerization tasks.

TABLE I: Wide range temperature of teeth during daily life

Temperature (°C)	*Hot Beverage*	*Hot Food*
Highest[a]	76.3	53.6
Mean Maximum[b]	46.4	41.6
Calculated Extreme[c]	61.4	50.2

a Highest temperature measured in one volunteer between the lower incisors.
b Mean maximum temperature ± standard deviation recorded by each electrode for all volunteers.
c Calculated extreme temperature obtained by adding two standard deviations to the mean maximum temperature measured *in vivo*.

TABLE II: Typical thermal treatments and intrapulpal temperature rise

Treatments	*Temperature Rise (°C)*	*References*
Laser assisted ablation	2.3—24.7	[22, 23]
Laser assisted caries prevention	1.2—4.0	[15]
Bleaching (without light/laser assisted)	0.1—1.1	[24]
Bleaching (without light/laser assisted)	1.1–16.0	[17, 25]
Polymerization of dental restorative materials	2.9–7.8	[10, 26, 27]
HSHPs cavity preparation (without water, high load)	16.4–19.7	[12, 28]
HSHPs cavity preparation (without water, low load)	7.1–9.5	[12, 28]
HSHPs cavity preparation (with water, high load)	2.2–5.9	[12,28]
HSHPs cavity preparation (with water, low load)	−1.8 (drop in temperature) to 5.0	[12, 28]

This paper is organized as follows: Section 2 describes the general structure of investigation and method. Section 3 illustrates the results of test measurements. We will also demonstrate the superiority of our scheme over the methods proposed by other researchers. In the last part, we conclude this paper.

2. Materials and Methods

2.1 General structure of the investigation

The details of our experimental setup for temperature measurement in tooth could be organized in four main modules as follows:

Module1. In this module, we provide a serial communication between PC and the visualization system, which sends the acquired data from the circuit to PC via a microprocessor. This module consists of three sections: the data acquisition, processing and analysis system.

Module2. We have an embedded tooth in the chamber of isothermal liquid flowing that implements the heat transfer from the pulp and vascular tissue in gum.

Module3. For adjusting the temperature of the chamber and keeping the condition of experiment close to the real case, we use a thermo-cycle box, which has a stabilizer system.

Module4. Two main heat sources are used; first is direct heat from the polymerization light on the surface of the tooth and the second is the heat transfer through the tooth pulp placed inside the water chamber.

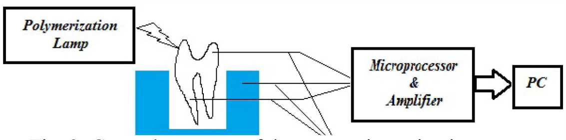


Fig. 2: General structure of the present investigation

Figure2 shows the general block diagram of the process and figure3 presents the completely portable real system. Before putting the tooth into the socket of the chamber, the micro-

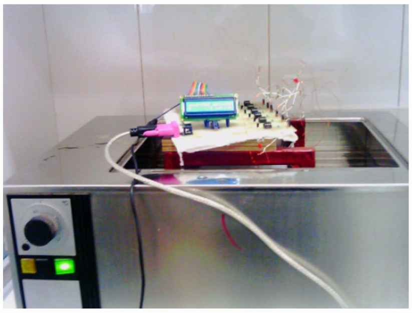


Fig. 3: The completely portable real system

thermocouples, which sense temperatures of the various points of the environment and tooth layers, are assembled. The applied micro-thermocouples are Type K and the wire equals 0.25mm (0.010 in). In order to eliminate the effects of thermocouples on each other and preventing the creation of new junctions, we cover those with a special material, which provides electrical and thermal isolation. In this particular case, we use six micro-thermocouples that three of them have an important role in contrast to others. These thermocouples are inserted at three certain points: 1. inside the tooth (pulp) (T1) 2. On its surface (T3) and 3. Inside the tooth tissue but outside of the water bath and far from the light (T5). We placed three remaining micro-thermocouples in the environment of tooth (T2), in the water bath (T0), on the tooth surface and close to the light source (T4) (as illustrated in figure 4), Due to using the micro-thermocouples with small dimension, the transient errors of measuring temperature are optimized.

The data acquisition module consists of three main sections. First is the amplifier subsystem, which amplifies the output voltage signal of the thermocouples, rejects all noise signals, and provides a clear appropriate signal for the second part. The next section is a microprocessor that converts analog signal to digital, calculates average of one thousand samples and finally the digital data are sent via a serial communication port to PC. In fact the signal being measured are handled by a portable PC (laptop) equipped with a serial connection. This is an interface, which is supplied by a microcontroller (ATmega16) for multichannel temperature and low voltage signal measurement from micro-thermocouples. A quadratic equation extracts the real temperatures from the received digital temperatures (used as a gold standard) which are then recorded in the system memory.

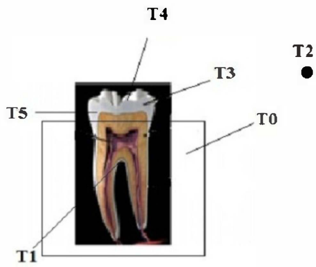


Fig. 4: The location of Micro-Thermocouples

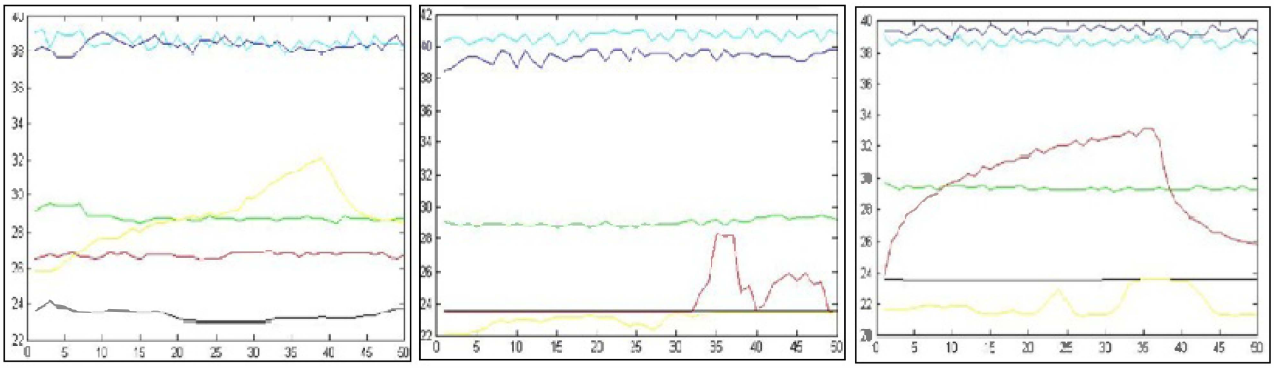
A computer program (GUI) is utilized for illustration of results on computer screen and providing a real time graph. This method makes an online control of the conditions of the experiment. The completely portable system of data acquisition was designed in such a way that it can be used for measurements in dentist surgery rooms.

3. Results and Discussion

There are several factors about heat transfer in human teeth. However, there are at least two mechanism of heat transfer away from the tooth. The first is the direct heat exchange between the light polymerization source and the tooth surface placed in the chamber, another one is the heat transfer through the pulp of the tooth, which is located in the water bath. There are a number of reports on investigating the whole tooth in the air [21], [22], [23] and investigations with the tooth placed in a gel of stabilized temperature [24], [25]. In both experiments, the conditions of the experiments are not sufficient and the reliability of the temperature measurements could be disputable. Meanwhile, there is lack of literature reports on experiments with modeling of the heat transport through the tooth pulp. The polymerization light is glinted on the tooth surface. Base on the cure procedure, the frequent time for glinting on the tooth is between 20 to 30 seconds, minimum and maximum respectively.

According to the extended research, the thermal conductivity of the tooth pulp is quite similar to the cupper element; therefore, it is decided to model the heat transference through the pulp by a cupper shaft.

Fig. 5: Typical recordings of transient temperature



a) Mode: Low Time: 30Sec.

b)Mode: Soft Time: 30Sec.

Fun[...] ys the role o[...] Test measurements were performed for a tooth equipped with six micro-thermocouples (Figure.4). The tooth was mounted on a plastic plate and then placed between footstool legs in water bath. Temperature of running water bath was stabilized at 37±1 °C, which corresponds to the anticipated mean sub-gingival temperature.

The tooth investigated was subjected to measurements twice: in the courses of 20seconds and 30seconds exposition time. During the test, the effect of three modes (Low, High and Soft) of polymerization lamp was compared. The popular polymerization lamp BluePhase (g2) was utilized which generates a significant temperature rise in three modes. In every mode, the acquisition data system recorded the temperature signals regarding to exposition time of the tooth to the lamp. Formerly, we cited that the number of applied micro-thermocouples is six, however here we demonstrate the results of four of them. Typical recordings of transient temperature of two main modes (Low and High) are illustrated in figure5. The graphs given present the effect of using polymerization lamp in the low, Soft and high modes in the frequent exposition time (30Sec.). In these recordings, green graphs show T1 data, red graphs belong to T4. The dark blue graphs illustrate temperature of T0, the yellow and black graphs present T5 and T2 information, respectively. In addition, we assume and see that the temperature of the tooth surface (T3) equals to the source temperature (T4). As a result, we did not apply T3 into tooth and in procedure experiment, it was in water chamber. In each of the three graphs, the second micro-thermocouple temperature (T2) remained steady approximately at 24 °C and did not change because it reports the temperature of air. This stabilized temperature trend also occurred for the micro-thermocouple number five (T5) especially in two of graphs (5.b and 5.c) while in the first graph, the temperature changes corresponds to the T5 is perceptible. As we can see in fig.5.c and fig.5.b, the temperature of pulp fluctuates between 28 to 30°C while in the last graph, the temperature of pulp is roughly 30°C.

To show the temperature changes process in the tooth as a function of lamp parameters table_3 is formed which illustrates the average values of temperature measured in all measuring points. It can be seen that heat from the lamp in the low mode and soft mode does not cause a significant rise in temperature of the pulp and surface of tooth. In the high mode, the temperature of the fifth point (T4) increased substantially from 24 to 33 while other point had not changed considerably. What more in the soft mode, the temperature of this point has changed gradually from 24 to 28 °C.

As we expect, the copper wire leads to a steady state in the recorded temperature. These results are considered as preliminary.

4. Conclusion

An experimental investigation about the heat transfer phenomenon in human teeth is presented in this paper. With this particular method, the tooth temperature changes trend in the curing procedure can be recorded. In addition, this system is easy to handle in the laboratory environment and the obtained results are reliable. As demonstrated in the experimental results, the direct heat exchange between the lamp and tooth is undeniable, especially in the high mode.

TABLE III: The average values of the temperature measured in all points

	Time	*T0*	*T1*	*T2*	*T3*	*T4*	*T5*
Low	20 Sec.	36.30	36.93	23.43	23.43	23.43	24.52
	30 Sec.	36.73	37.89	23.43	23.43	23.43	24.46
High	20 Sec.	35.69	33.33	23.43	36.79	23.43	23.43
	30 Sec.	36.09	36.72	23.43	34.98	23.43	23.43
Soft	20 Sec.	36.76	38.03	23.43	23.43	23.43	23.78
	30 Sec.	35.50	33.77	23.43	28.58	23.43	23.43

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