Heat transmission along the surface of a dental implant

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A mini-thesis submitted in partial fulfilment of the requirements for the degree of Magister Chirurgiae Dentium (MChD) in the Department of Restorative Dentistry, Faculty of Dentistry, University of the Western Cape.

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May 2009

Declaration

I, Zaheed Patel, declare that the work contained in this research report is my own original work. I have not previously submitted this research report to any university or institution for a degree or examination.

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_________ Day of ____________ of 2009

Acknowledgements

The completion of this thesis could only have been achieved with the assistance and support of many individuals. I wish to express my sincere thanks and gratitude to those who have made this research project possible.

To my supervisor and academic mentor, Professor G Geerts, Head of the Postgraduate Prosthodontics program at the University of Western Cape, your ceaseless support, drive and guidance have paved the way along my academic path. I am extremely grateful for your patience and understanding.

To the following people for rendering their required services:

- Professor R Madsen : Statistical advice
- Professor M Moola : Financing of project
- Mr Derek Abrahamse : Building of the experimental implant model
- Southern Implants : Kind sponsorship of the implant and abutment
- Ashvaak Dawood : Electronic advice and electronic engineering
- Ayesha Patel : Computer

Dedication

I wish to dedicate this mini-thesis to my late grandmother, Amina Patel, who had taught me that nothing in life is impossible. To my wife, Ayesha Patel for her continued understanding, love and support during those demanding times.

Abstract

Objectives: Temperature changes along an implant body have not been widely studied. The objectives of this *in vitro* study were (i) to establish if the temperature of the abutment *influences* the temperature of the implant surface, (ii) to establish the *temperature transmission* from abutment to implant body, and (iii) to establish for what abutment temperature the *critical time/temperature threshold* of 47^{o}C for 1 minute at implant level is reached.

Materials and method: Eight K-type thermocouples were attached to an abutment/implant configuration, mounted in a thermostatically controlled environment. The abutment was exposed to hot water. The temperature at each thermocouple along the implant was logged over a maximum period of 10 minutes using appropriate software. The test was repeated 200 times. A logistic regression model was used for the analysis of the time/temperature databases.

Results: There was a positive correlation between the temperatures of the implant and its abutment, albeit with a time delay. Critical threshold values for bone necrosis were reached. The effective dose 50 was estimated at 62.3^{o}C (95% confidence interval estimate): for an abutment temperature of 62.3^{o}C there is a 50% chance that 47^{o}C for 1 minute at implant level is reached.

Conclusion: The results of this *in vitro* study support the hypothesis that abutment temperature is transmitted to a dental implant body. Results of *in vitro* studies should be interpreted with caution. However, clinicians should be aware of temperature changes along implants and the potential risk associated with this.

Keywords

1. Dental implants
2. Heat transmission
3. Thermocouple

Definitions of key terms

Apoptosis

Apoptosis is a co-ordinated, innate process by which cells systematically dissemble and degrade their structural and functional components to complete cell death.

Data logger

A data logger is any device that is used to read various types of electrical signals and can store data in an internal memory for later download to a computer.

Necrosis

Necrosis is known as cell death following injury.

Osseointegration

Osseointegration may broadly be defined as the dynamic interaction of living bone with that of a biocompatible implant in the absence of an interposing soft tissue layer.

Osteoblast

An osteoblast is a bone-forming cell producing bone matrix (osteoid).

Thermocouple

A thermocouple is the junction of two dissimilar metals which results in a potential difference that can be measured.

Table of contents

Addendum

Example of a complete time/temperature database for test 1

List of figures

1. Introduction and literature review

1.1 Introduction

Dental implants are a predictable treatment modality for the rehabilitation of partially and completely edentulous patients. Ten-year survival rates of >95% and 15-year survival rates of >92% have been reported (Adell *et al.*, 1990). The biological concept of osseointegration was first introduced by Brånemark *et al.* in the 1960s (Brånemark *et al.*, 1969). Since its introduction, the term osseointegration has been successively redefined, the common denominator being an inanimate metallic structure anchored long-term in living bone under functional loading (Triplett *et al.*, 2003).

1.2 Problem statement and purpose of the study

While the importance of heat control during bone surgery has long been recognized, the effect of possible temperature changes along an implant and their impact on healing tissue and osseointegration is poorly characterized. Only seven publications investigating the transmission of heat along dental implants could be found (Gross *et al.,* 1995; Ormianer *et al.*, 2000; Wong *et al.*, 2001; Kreisler *et al.,* 2003; Nissan *et al.,* 2006; Feuerstein *et al.*, 2008; and Ormianer *et al*., 2009). In cases of single-stage surgery and immediate loading, where freshly placed implants are left exposed to the oral environment, it may be speculated that temperature changes along the dental implant can occur and have an influence on the healing process.

The purpose of this study is to address this lack of knowledge and to establish if temperature changes along the surface of a dental implant do occur.

1.3 Literature review

1.3.1 *Healing of bone and osseointegration*

Endosseous healing following implant placement happens in a similar manner to that following other forms of bone injury. The sequence of events can be divided into haematoma formation, clot resolution, osteogenic cell migration, formation of new bone and then remodelling. A summary of these processes is written by Hell (2007) in his dissertation, as follows:

> *"a) Haematoma formation - the implant surface becomes coated with plasma proteins, followed by platelet adhesion, activation and degranulation. A fibrin clot rapidly forms, providing a physical barrier to prevent further bleeding; additionally it serves as a reservoir of growth factors and cytokines (Gemmel and Park, 2000).*
>
> *b) Intense cellular activity follows the infiltration of the clot by neutrophils, monocytes and fibroblasts. This intensity leads to some anaerobic metabolism, creating lactic acid, reducing the pH and creating*

an oxygen gradient that is chemotactic for endothelial and mesenchymal cells.

c) Fibrinolysis occurs with the formation of a loose connective tissue stroma that supports angiogenesis. From about 4 days up to approximately 3 weeks granulation tissue forms, the initial matrix gradually being replaced by a collagen-rich matrix, which precedes bone formation.

d) Osteoblasts secrete non-collagenous bone proteins, primarily osteopontin and sialoprotein, onto the implant surface. Calcium binding occurs at the binding sites on the proteins, followed by the crystal growth phase. The collagenous matrix becomes mineralised in a rapid and asynchronous manner, leading to the formation of woven bone. This process predominates within the first 4-6 weeks after implant placement. During these initial healing stages necrosis and resorption of traumatized bone from both the osteotomy preparation and implant placement occurs.

e) After about 4 weeks, the woven bone is gradually replaced by lamellar bone with haversian architecture. Having collagen fibrils arranged in parallel layers with alternating courses, the lamellar bone has high strength, which by virtue of being in close contact with the implant surface gives the implant the necessary rigid fixation to accommodate loading. From about one month after surgical placement the bone begins to remodel as a process that occurs throughout life. Remodelling reflects functional adaptation of the bone structure to load, and occurs by *osteoclastic resorption and lamellar bone deposition that are coupled both in space and time (Stanford and Brand, 1999)."*

Definition of osseointegration

Osseointegration has been defined by Albrektsson *et al*. (1981) as a "direct functional and structural connection between living bone and the surface of a load-bearing implant". The definition refers to a physical integration of the machined implant and the bone, macroscopically at the level of the implant threads and microscopically at the level of the machining irregularities (Puleo and Thomas, 2006).

1.3.2 *Loss of integration*

What is understood by loss of osseointegration?

Implant failure or loss of osseointegration is defined as the inadequacy of the host tissue to establish or maintain osseointegration (Esposito *et al.*, 1998 as cited by Pye *et al.*, 2009). Implants can be described as *failing* or *failed*. A failing implant demonstrates a progressive loss of supporting bone but is clinically immobile whereas a failed implant is clinically mobile.

Traditional protocols for osseointegration report high success rates being in the range of 90-95% (Esposito *et al.*, 1998 as cited by Pye *et al.*, 2009). Recent developments include single-stage surgery and immediate function of dental implants. In single-stage surgery the dental implant remains uncovered after insertion in the bone, and thus, exposed to the oral environment. The success rates of osseointegration for single stage and immediate loading are reported to be only 90% (Attard and Zarb, 2005). Reasons for lower success rates are blamed on infection and lack of primary stability (Attard and Zarb, 2005).

Alvim-Pereira *et al.* (2008) stated that failure of the osseointegrated implant should be understood as a complex, multifactorial process.

1.3.3 *Oral environment temperature changes*

Temperatures in the mouth may vary depending on the temperature of ingested foods and beverages. Surface temperature of intra-oral structures ranging between $0^{o}C - 67^{o}C$ has been measured (Wong *et al.*, 2001). Others showed that the temperature produced intra-orally during hot water consumption may reach $67^{o}C$ (Palmer *et al.*, 1992) and even $77^{o}C$ (Barclay *et al.*, 2005). Feuerstein *et al.* (2008) measured a maximum temperature value of $76.3^{o}C$ for hot beverages and $53.6^{o}C$ for hot foods. Coffee above $68^{o}C$ was too hot to sip, but it could be sipped with minimum discomfort between $60^{o}C$ and $68^{o}C$ (Plant *et al.*, 1974 as cited by Feuerstein *et al.*, 2008). The highest tolerable temperature is subjective and varies considerably among the population. It is probably affected by factors such as the degree of keratinisation of the oral mucosa and age (Feuerstein *et al.*, 2008). Some areas in the mouth are more susceptible to temperature changes than others.

An *in vivo* study found that the consumption of cold and hot drinks caused different temperature variations at different sites in the oral cavity (Airoldi *et al.*, 1997). The highest temperature was evident in the interincisor region of the upper arch, as this is the first site of contact (Airoldi *et al.*, 1997). Feuerstein *et al.* (2008) observed a maximum temperature of 76.3°C between the lower incisors. A lower temperature measurement was evident in the second premolar in the right and left positions of the upper arch. These measurements were only applicable to a single sip and multiple sips (Airoldi *et al.*, 1997). However, when a sip is being consumed, followed by a rinse, then the temperature values of the lower arch were higher compared to the mean temperature of the upper arch, being attributed to gravity i.e. the lower dental arch is exposed to higher temperatures than the upper dental arch, except in the interincisor position (Airoldi *et al.*, 1997). Whilst consuming a hot drink, the temperature reaches a maximum in the temperature specific sites and recovers to oral temperature in an exponential way (Airoldi *et al.*, 1997). Studies by Feuerstein *et al.* (2008), Palmer *et al.* (1992), Youngson and Barclay (2000) showed that less extreme temperatures were measured along the posterior teeth but they were sustained for longer than in the incisor region.

Moore *et al.* (1999) found that temperatures vary considerably for an individual over a 24 hour period. Significant racial differences were also evident: temperatures recorded from the Asian group were higher than from the Caucasian group (Moore *et al.*, 1999). Conversely to Airoldi *et al.* (1997), Moore *et al.* (1999) also found that the premolar site temperatures were higher than those of the incisor site and the temperatures at both sites had a high correlation (Moore *et al.*, 1999).

1.3.4 *Heat transmission along dental implants*

Usually, an implant is connected to a prosthetic superstructure by means of a titanium abutment. Implants and transmucosal structures are made from metal alloys. Therefore, a potential continuous thermal conduction pathway is created between the oral cavity and deeper parts of the jaw bone (Wong *et al*., 2001). An implant body can store heat and act as a 'sink' through which heat may be dissipated into the adjacent bone and soft tissue during or following osseointegration (Wong *et al*., 2001).

Only seven publications directly relevant to the subject of my research could be found. A summary of these 7 publications follows:

The earliest paper on temperature changes along dental implants was published by Gross *et al.* (1995). They looked at heat generation *in vitro* at the implant surface caused by abutment reduction with diamond and tungsten burs with standard turbine coolant. Thermocouples at the cervix and apex of the implant measured the temperature changes. Mean temperature increases were 1^{o}C and 2^{o}C, with the tungsten burs generating more heat. However, these temperature increases are unlikely to cause irreversible bone damage and compromise osseointegration.

In 2000, Ormianer *et al.* used thermocouples to investigate heat generation at the implant surface caused by the exothermic setting reaction of autopolymerizing acrylic resins applied to an abutment connected to an implant *in vitro.* A maximum temperature increase of 6^{o}C at the cervical part of the implant was recorded. With the base temperature of the implant at 37^{o}C this meant a temperature of 43^{o}C at the implant surface. Hyperemia and increased capillary filtration can occur at 41^{o}C to 43^{o}C (Eriksson *et al.*, 1982, 1984; Eriksson and Albrektsson, 1983).

To investigate heat transmission along an implant body, a computer model was used by Wong *et al.* (2001) to simulate the effects of different temperatures. They discovered that a temperature of 47^{o}C was achieved after a time interval of 1 second at distances of 1.29mm, 3.45mm and 4.54mm along an implant body after temperature pulses of 50^{o}C, 60^{o}C, and 70^{o}C, respectively.

The fourth paper, by Kreisler *et al.* (2003), investigated temperature changes at the implant-bone interface during simulated implant surface decontamination using laser. Temperature elevations during irradiation were measured using K-type thermocouples. Critical threshold temperature of 47^{o}C was exceeded after 9 to 30 seconds, depending on the energy used.

Nissan *et al.* (2006) investigated temperature changes at the cervical and apical part of an implant surface using impression plaster. Temperature changes in the range of 2^{o}C to 3^{o}C were seen, which were considered clinically insignificant.

In 2008, Feuerstein *et al*. studied *in vivo* maximum temperatures produced intra-orally while consuming very hot substances. These values were used in an *ex vivo* model to assess the temperature changes along the implant-bone interface by means of thermocouples at 3 levels of the implant body. The maximum temperature value measured intra-orally was 76.3^{o}C for hot beverages. The simulation of high-temperature conditions caused an immediate increase in temperature at the abutment–implant interface which was high above the 47^{o}C threshold of bone necrosis as determined by Eriksson and Albrektsson (1983). At the mid-implant and apical level, there was a delayed increase in temperature that reached the 42^{o}C threshold of transient changes in osteoblasts as determined by Li *et al.* (1999).

The seventh publication, by Ormianer *et al.* (2009), measured temperature changes of implants *in vivo.* Thermocouples attached to the abutment, inside the implant at implant/abutment level, and at a depth of 7-8 mm of successfully integrated implants measured temperatures while subjects drank 300ml of hot tea. Temperatures higher than 40^{o}C were measured in almost all locations as well as 42^{o}C and 47^{o}C in some locations. A linear correlation of temperature measured at abutment level and lower levels was found.

The “oral burn syndrome” can be defined as the harmful effects to soft tissues around dental implants and other dental appliances following ingestion of hot liquids and food (Wood and Vermilyea, 2004; Moore *et al.*, 1999). This effect is similar to the known harmful effect of overheating bone during the placement of implants. Since, metals are good conductors of heat, the amount of metal in an implant will accelerate heat transfer to the supporting tissues. This could have a negative biological effect (Wood and Vermilyea, 2004).

1.3.5 *Measuring temperature and heat conduction*

In dentistry, both thermocouples and infrared thermography are used in temperature studies. Thermocouples have been the traditional gold standard of temperature measurement (Mc Cullagh *et al*., 2000). The limitation of thermocouples is that they measure temperature only at the point on the surface it is contacting. On the other hand, infrared thermography shows temperatures over larger surface areas by means of colour representation. However, Mc Cullagh *et al*. (2000) in a study on heat generation on root surfaces during thermal condensation confirmed that the use of thermocouples was the more accurate method.

The transfer of heat along a metal rod or bar is treated in thermodynamics as thermal conduction. Wong *et al.* (2001, citing Rogers *et al*., 1992) describe thermal conduction as follows: the thermal conductivity, k, is defined as the rate at which heat is transferred through a material resulting in a temperature change of ΔT across surface area A. Then $k = QA/\Delta T$, where: Q is the quantity of heat transferred (Watts); A is the area (m^2); and ΔT is the change in temperature (K).

Most dental implants are made from grade 4 commercially pure titanium. For a metal, the thermal conductivity of titanium alloys is relatively low. Recent work has indicated that the value of thermal conductivity for commercially pure titanium alloy is 22.4 W m^2 K^{-1} (Wong *et al.*, 2001).

Dental implants are not solid metal beams, but come in different sizes and shapes which have different interface connections with prosthetic components and superstructures. Therefore it appears simplistic to describe thermal conductivity of an implant in the clinical setting by means of a mathematical model only.

Albrektsson *et al*. (2008a) criticized the Nobel Direct® (Nobel Biocare) implant design because it causes unacceptable bone loss. This implant system is a one-piece design. It is placed by a punch procedure through the soft tissue and followed by grinding down the superior portion *in situ* with potential heat and vibration trauma to the tissues. In a multicentre study, analyzing 550 Nobel Direct implants placed by experienced users, about 25% of all implants have demonstrated >3mm of bone loss at only 1-year follow-up. An additional 9.9% of implants have failed. This is a higher failure rate than generally accepted. Albrektsson *et al.* (2008b) speculated that the heat generated during preparation of the abutment *in situ* might contribute to the negative consequences.

1.3.6 *Influence of heat on bone metabolism*

The placement of an implant requires the preparation of an implant site. During bone surgery, the control of heat has always been an important issue. The effect of heat on bone has been studied extensively (Benington *et al.*, 1996). Heat generation in the drilling process is one of the main causes of the failure of osseointegration at the bone-implant interface (Li *et al.*, 1999).

Overheating during preparation of implant sites can result in bone necrosis causing early implant failure due to lack of osseointegration (Duyck and Naert, 1998). Temperature changes at the cervical implant during performance of clinical procedures *in vitro* were also studied (Ormianer *et al.*, 2000). Therefore, implant site preparation is performed under irrigation to control the temperature during surgery. However, there is no information on the temperature developed at the implant bone interface during consumption of hot substances.

Several factors suggest that temperature rises of about 10^{o}C might be harmful. Alkaline phosphatase is an enzyme found in the membrane of osteoblasts and is a useful primary marker of osteoblast activity. Although it can maintain its biological activity over a wide temperature range, the protein becomes denatured above 50^{o}C and is irreversibly damaged (Lundskog, 1972 as cited by Wong *et al.*, 2001).

The following threshold values for preventing bone damage have been reported: a temperature of 47^{o}C for the duration of 1 minute was found to affect osteoblast activity; temperatures above 50°C for any time values caused irreversible damage (Wong *et al.*, 2001; Eriksson and Albrektsson, 1983). Bone necrosis also occured when a temperature of 40°C is applied for 7 minutes (Misch, 1999; Duyck and Naert, 1998). This time-temperature ratio is important.

Heat shock at 42°C induced transient changes in osteoblasts (Li *et al.*, 1999). There was disruption of the actin filaments, and membrane ruffling at the cell periphery (Li *et al.*, 1999). The degree of disruption increased increased with temperature.

Heat shock at a temperature above 45°C, as exemplified by that at 48°C, induces irreversible responses such as necrosis and apoptosis. The duration of heat shock is also important, since a prolonged elevation in temperature above 44°C has been correlated clinically with an increase in implant failure (Calder *et al.*, 1995). Osteoblasts treated at 45°C could recover without an increase in the rate of apoptosis, but those treated at 48°C showed an increase of the apoptosis rate to 10%, suggesting that the protective mechanism was unable to repair the damage at 48°C or suppress the apoptotic program in some of the cells (Li *et al.*, 1999).

The critical time/temperature thresholds may also vary with other factors such as cell type. The treatment of endothelial cells at 48°C for 10 minutes does not induce cell death (Eriksson *et al.*, 1984). In murine lymphoma cells a temperature of 43°C is sufficient to induce apoptosis and 45°C is enough to induce necrosis (Van der Waal *et al.,* 1997 as cited by Li *et al.*, 1999). In human polymorphonuclear leukocytes, phagocytic function is suppressed at and above

44^{o}C for 15 minutes (Melinikov *et al.*, 1998 as cited by Li *et al.,* 1999). In rat neuron cells, heat shock at 45^{o}C for 30 minutes induces necrosis and apoptosis in more than 50% of the cells (Li *et al*., 1999). This explains to us that specific cell types have specific temperature thresholds. Hence, for osseointegration, it is important not to exceed the temperature threshold of osteoblast cell types.

2. Methods and materials

2.1 Aim

The aim of this *in vitro* study is to perform a quantitative, descriptive analysis of temperature changes along the surface of an implant body by exposing an implant abutment to hot water simulating the temperature of hot beverages.

2.2 Objectives

a) To establish if the temperature of the abutment *influences* the temperature of the implant surface.

b) To establish the temperature *transmission* from abutment to implant body.

c) To establish for what abutment temperature the *critical time/temperature threshold* of 47^{o}C for 1 minute at implant level is reached.

2.3 Null hypotheses

a) The surface temperature of the implant is not affected by the temperature of its abutment.

b) There is no time delay between recording the maximum temperature of the abutment and the maximum temperature of the implant.

c) The temperature of 47^{o}C will not be reached at any implant level regardless of the temperature of the abutment.

2.4 Methodology

2.4.1 *Study design*

An implant (surface enhanced, external hex) of 15 mm in length and a diameter of 3.75mm (IBS15, Southern Implants, Irene, South Africa) was placed in a jig. The implant had a 5mm abutment (TB3N, Southern Implants, Irene, South Africa). A teflon diaphragm of 250 micron thickness was secured around the neck of the implant creating 2 chambers. The upper chamber served as a container for the hot water. (Figure 1). Eight K-type thermocouples were used for the experimental model. One was placed in the hot water chamber. The other 7 were attached to the implant model by means of epoxy adhesive (Pratley Steel®, Pratley®, Kenmare, South Africa) at the following sites:

- One was connected to the implant abutment, also above the teflon diaphragm (channel 2)
- One to the implant collar,1mm below the teflon platform (channel 3)
- The other five were placed in 1mm increments along the body of the implant towards the implant apex (channels 4 to 8).

Due to the sensitivity of the thermocouples, they were each isolated with silicone putty (Flextec101, Henkel, Alrode, South Africa). The apical part of the implant was in contact with water located in a petri dish regulated at a temperature of 37°C. This temperature was achieved with a mini heater element regulated by a

Proportional-Integral-Derivative (PID) controller (Rex-C100, RKC Instrument Inc, Ohta-ku, Japan). The PID controller had an independent sensor and regulated the water temperature consistently. This simulated the bone temperature.

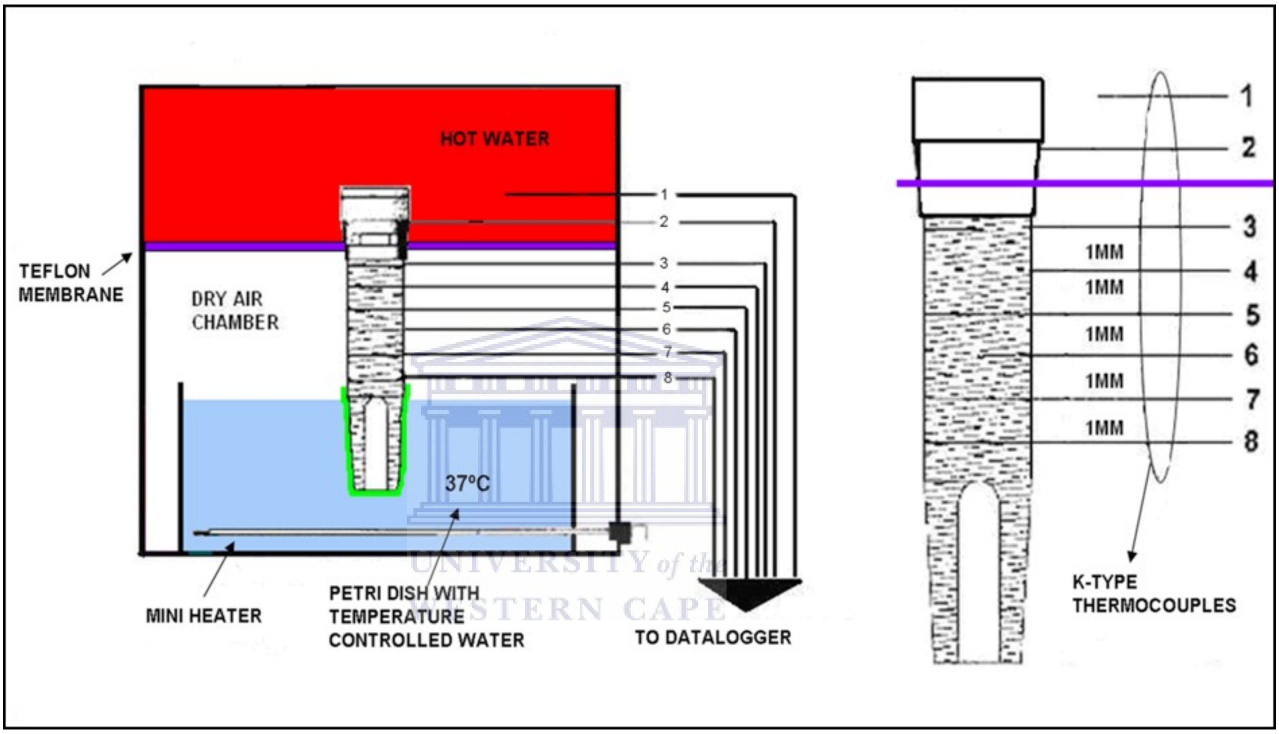

Figure 1: Graphical presentation of implant model with the position of the 8 thermocouples. The green line indicates the silicone lining isolating the tip of the implant from the water.

The apex of the dental implant body in contact with the petri dish was also isolated with silicone putty to prevent hygroscopic uptake of water along the external surface of the implant body. This water contamination might have affected the potential difference (PD) between the different thermocouples.

Communicating wire leads were connected to the thermocouples at one end and to a data logger (Picolog Data Logger®, Pico Technology, Cambridgeshire, United Kingdom) at the other end. (Figure 2). The data logger was connected to the computer via a USB cable. The computer was a Pentium 4, core 2 duo®, 2 gig ram, 1.8 GHz processor. Dedicated analytical software to the data logger to measure and record accurate readings for each thermocouple was installed (Picolog Recorder for Windows® XP Professional version 5.13.9). The thermocouples would relay a voltage difference from a specific site to the data logger. The data logger would interpret voltage difference and convert it from an analogue to a digital signal. This signal would then be relayed by a USB cable to the computer and interpreted by software and converted into digital graphs and spread sheets. These graphs and spread sheets would then be representative of the different temperatures over time at the different sites along the implant surface. The data logger and software were factory calibrated.

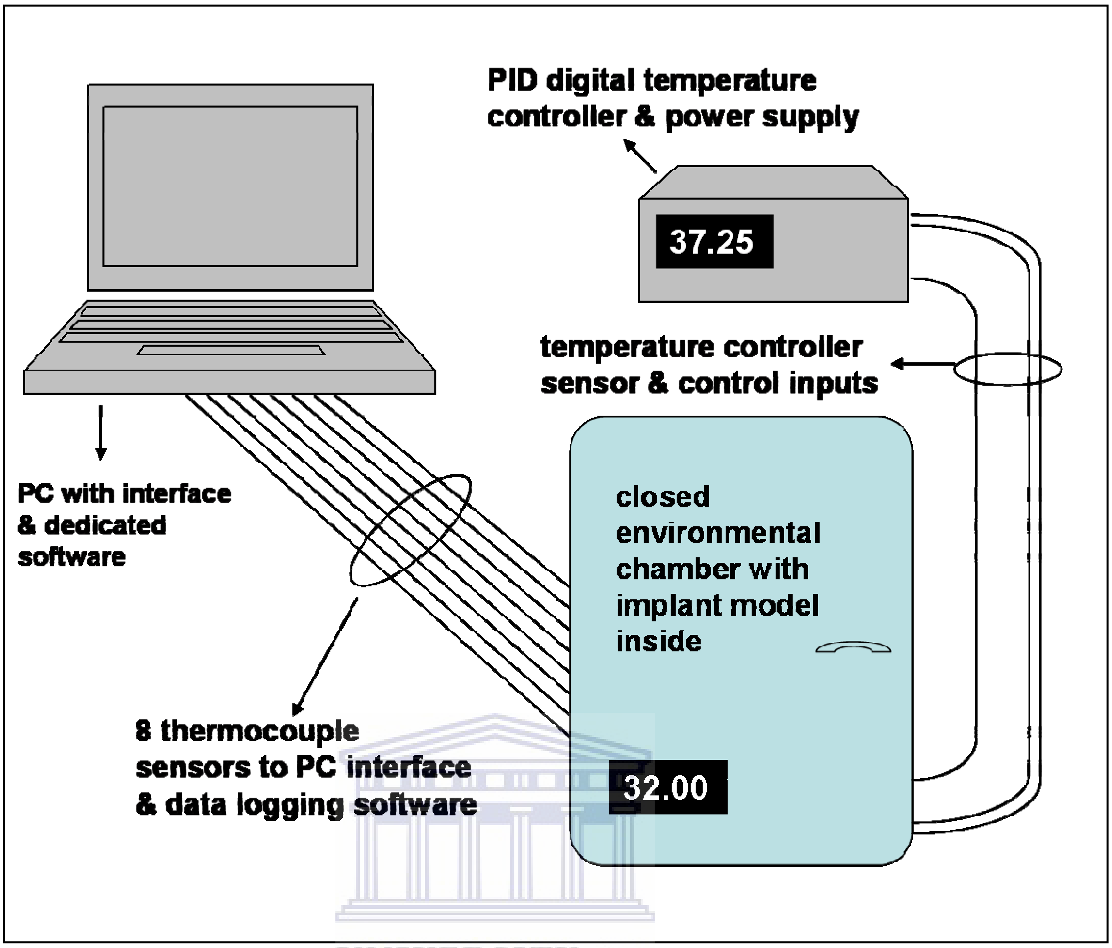

Figure 2: Diagram of data capturing equipment.

Thirty millilitres of water with a temperature range of 51°C to 83°C, checked with a mercury thermometer, was injected in the upper chamber. The water remained inside the chamber for the duration of the test (600seconds). As the hot water came into contact with the abutment, the temperature changes were measured as a PD across all thermocouples. The information was converted to temperature versus time graphs and charts on the computer. After the test, the water was removed from the upper chamber and the temperatures of the abutment and implant were allowed to return to 37ºC. This procedure was repeated 200 times.

The entire apparatus with the implant body, water chambers and thermocouples was housed in a temperature controlled chamber that maintained a constant temperature of 32^{o}C. This chamber ensured a controlled test environment, as the thermocouples are sensitive to temperature variations that could arise from factors such as room air conditioning systems or a wind draft.

2.4.2 Definition of terms

The identification of the following temperatures and time periods are strategic to the analysis of the results:

Max2: maximum recorded temperature by thermocouple 2 (channel 2)

Max3: maximum recorded temperature by thermocouple 3 (channel 3)

Total_time47: time period that the temperature was at or higher than 47^{o}C

Time2_47: refers to the time interval between max2 and the first time 47^{o}C is measured by thermocouple 3

Hot2long: this variable takes on the value 1 if the total time is at or higher than 47^{o}C for 60 seconds or more, and the value 0 if the total time at or above 47^{o}C is less than 60 seconds (including the cases where it never reached 47^{o}C)

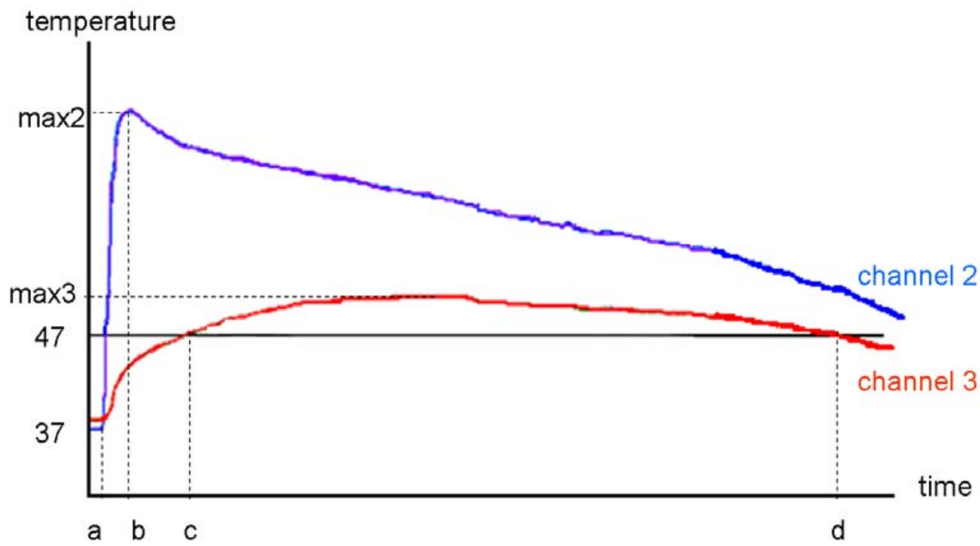

Figure 3: Graphical presentation of time temperature graph for channel 2 and channel 3.
max2 = highest temperature registered on abutment; max3 = highest temperature registered on implant; a= introduction of warm water in upper chamber; b = time when maximum temperature is reached by abutment. This represents 0-time for each test; c = time when 47ºC is reached for the first time by implant; d = time when 47ºC is registered for the last time on the implant; c-d = total_time47. b-c = time required from start of test (0-time) to reach 47ºC on the implant or time2_47.

2.4.3 Sample size

200 test series were performed.

2.4.4 ***Sampling procedure***

The settings for the temperature recording were as follows: 1 temperature recording at least every 3 seconds for a duration of 600 seconds for each channel. The test was started just before the hot water was introduced into the upper chamber. The test ended automatically when 600 seconds was reached. This gave a total of at least 200 temperature readings for each channel.

2.4.5 *Data collection*

The data collected using the dedicated temperature recording software was copied into MSExcel®. The tests were numbered and ordered creating one MSExcel® spreadsheet before being analysed using statistical software SASv9 (SAS Institute Inc., Cary, NC, USA).

2.4.6 *Reliability*

The percentage error for temperature measurement is +/- 0.1°C and 0.3% of the readings as per manufacturer's specification hence implying the degree of inaccuracy of the thermocouple.

2.4.7 Data analysis

Using logistic regression, the log odds of P(Y=1) as a linear function of X, was modelled, the value of X was estimated with the probability that Y=1, was 0.5. In other words, the temperature X, at which there is a 50-50 chance that 47ºC is exceeded for at least 1 minute, is estimated. This temperature is referred to as the effective dose 50 (ED50). Mathematically the logistic regression equation can be written as:

$$\log\left[\frac{P(Y=1\,|\,x)}{1-P(Y=1\,|\,x)}\right]=\beta_0+\beta_1 x$$

The logistic procedure in the statistical software SAS v9 was used to find the estimates of the parameters in the logistic regression model. By using the estimates of the parameters as well as the estimated standard errors, it is possible to get a point estimate of the ED50 as well as a 95% confidence interval estimate. The variance of the ED50 estimate was found by using the Delta method.

3. Results

3.1. Descriptive analysis

From the 200 tests, only 53 tests were used. The reason for using 53 tests was that the computer could not assimilate the live streaming data, and hence stalled during the recording process. This resulted in incomplete test runs. Of the 200 tests only 53 met the criteria of running for the full or close to the full test length.

For the purpose of this study, only the data produced by channel 2 (abutment temperature) and 3 (implant level 1 temperature) were analysed. The addendum shows an example of a complete time/temperature database for test 1.

The abutment temperature range was from 52.80ºC to 71.72ºC, with an average of 63.30ºC and a median of 63.57ºC. The implant temperature range was from 43.03ºC to 53.00ºC, with an average of 47.83ºC and a median of 47.96ºC. Figure 4 shows a summary of the various times and temperatures associated with each of the 53 tests. A dot (.) for a start or end time indicates that the temperature of 47ºC was not reached for that test.

test	max2	max3	n	max2time	max3time	start_ time	end_time	zero_ time	total_ time47	hot2long	time2_47
1	67.80	49.18	500	78	294	164	499	59	335	1	105
2	69.10	48.89	500	92	319	199	499	74	300	1	125
3	64.86	48.40	500	95	308	191	499	74	308	1	117
4	69.89	48.09	500	47	213	134	390	27	256	1	107
5	60.35	46.68	500	53	264	.	.	29	.	0	.
6	64.53	48.14	500	69	293	199	466	42	267	1	157
7	70.72	53.00	500	28	324	72	499	9	427	1	63
8	70.65	50.39	500	32	237	100	499	13	399	1	87
9	71.72	51.27	500	30	272	77	499	11	422	1	66
10	70.32	50.21	500	30	258	111	499	11	388	1	100
11	63.94	48.25	500	53	289	174	481	28	307	1	146
12	63.50	48.76	500	28	258	134	586	10	452	1	124
13	61.90	48.56	500	54	304	158	558	34	400	1	124
14	62.65	48.09	280	34	312	154	492	14	338	1	140
15	66.60	49.86	500	34	310	120	644	18	524	1	102
16	66.88	48.96	500	46	234	128	468	26	340	1	102
17	66.25	50.32	320	40	270	106	638	20	532	1	86
18	64.97	48.03	290	34	304	148	448	14	300	1	134
19	68.28	49.42	500	48	242	124	474	28	350	1	96
20	65.70	48.80	260	42	244	126	480	22	354	1	104
21	64.62	47.96	500	30	238	148	416	10	268	1	138
22	64.03	48.20	240	39	273	153	441	18	288	1	135
23	67.82	49.18	200	39	249	123	564	18	441	1	105
24	67.01	47.98	150	39	249	153	429	18	276	1	135
25	58.53	45.15	140	33	237	.	.	9	.	0	.
26	62.80	47.19	200	33	231	219	294	12	75	1	207
27	58.22	44.88	151	30	255	.	.	12	.	0	.
28	60.41	46.28	180	42	222	.	.	9	.	0	.
29	59.14	45.70	100	36	264	.	.	18	.	0	.
30	60.70	46.12	101	36	213	.	.	18	.	0	.
31	62.74	47.03	200	30	225	225	234	9	9	0	216
32	58.24	44.93	200	60	261	.	.	39	.	0	.
33	58.94	45.61	110	33	279	.	.	15	.	0	.
34	65.02	47.25	200	42	267	216	342	24	126	1	192
35	65.67	48.14	200	48	222	150	435	27	285	1	123
36	66.11	48.16	200	42	276	156	429	21	273	1	135
37	66.86	48.09	200	60	303	180	423	39	243	1	141
38	61.57	46.83	200	42	252	.	.	18	.	0	.
39	65.57	47.30	500	38	256	208	344	15	136	1	193
40	61.25	45.75	490	35	253	.	.	16	.	0	.
41	58.42	46.06	500	42	288	.	.	15	.	0	.
42	61.44	48.05	390	28	256	158	450	8	292	1	150
43	65.13	47.41	200	63	279	216	354	39	138	1	177
44	52.80	43.03	183	36	282	.	.	18	.	0	.
45	54.97	44.04	170	39	279	.	.	21	.	0	.
46	57.01	45.26	200	66	261	.	.	42	.	0	.
47	56.62	44.15	200	30	264	.	.	15	.	0	.
48	61.55	45.97	90	54	225	.	.	27	.	0	.
49	59.40	44.86	130	48	264	.	.	21	.	0	.
50	60.81	46.59	200	57	255	.	.	18	.	0	.
51	60.13	46.54	200	90	333	.	.	51	.	0	.
52	63.57	45.19	100	60	246	.	.	42	.	0	.
53	57.36	43.38	170	42	258	.	.	21	.	0	.

Figure 4: Summary results for all 53 tests.

max2 = abutment temperature; max3 = highest temperature at 1mm below implant collar; n = number of samples per test; max2time = time at which the maximum temperature occurred for max 2; max3time = time at which the maximum temperature occurred for max3; start_time = first time at which 47^{o}C or higher was recorded; end_time = last time at which the temperature was at 47^{o}C or higher; zero_time = first time that the temperature for channel 2 was 38^{o}C or higher; total_time = total_time47 = the difference between start time and end time; hot2long = takes on the value of 1 if the total time at or above 47^{o}C is 60 seconds or more and the value 0 if the total time at or above 47^{o}Cis less than 60 seconds; time2_47 = refers to the time taken from max2 to reach 47^{o}C on max3.

The shortest observed time to reach 47°C was 63 seconds. This was for test no 7. The maximum abutment temperature is highlighted in blue in the second column (max2) of figure 4 (70.72°C).

Figure 5 shows an example of a time temperature graph for test no 9. This test had the highest maximum abutment temperature (71.72°C). The horizontal black line represents the threshold value of 47°C. The blue line represents the abutment temperature, green the temperature of the implant 1mm below collar, red 2mm below collar and yellow 3mm below collar on the implant body. Within the context of this study, only the temperatures represented by the blue and green lines were statistically analysed.

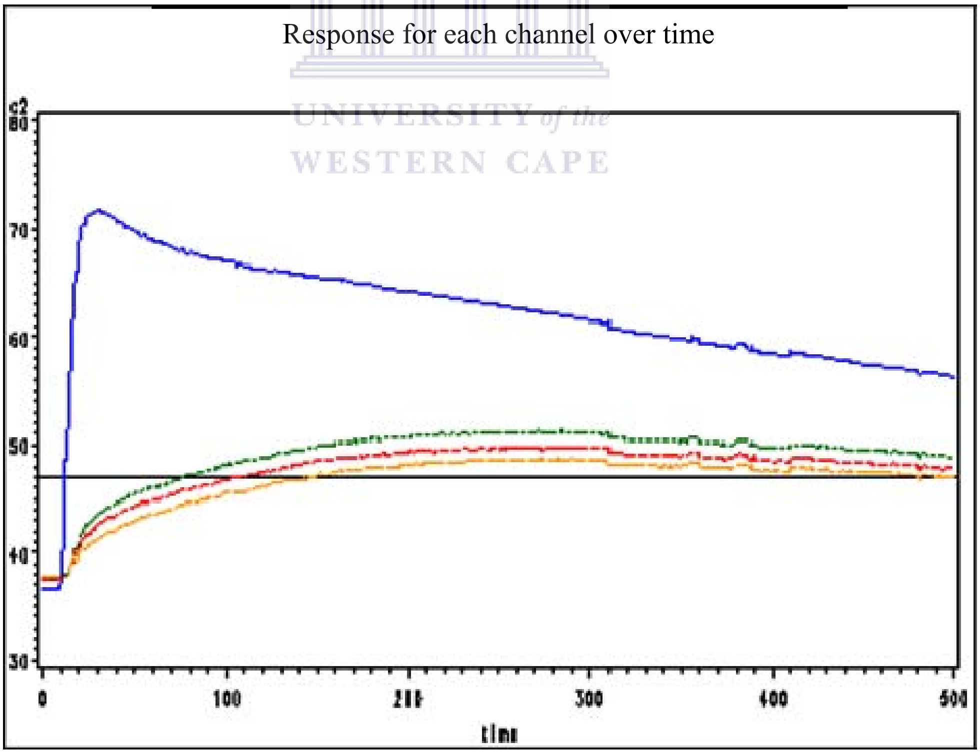

Figure 5: Time temperature graph for test no 9.

For an abutment temperature of 71.72°C (blue) there is a rapid increase in temperature along the implant body at the first millimeter (green). The temperature stays above 47° C for the whole duration of the test for both channel 2 and 3. We observe that channels 4 and 5 also registered temperatures above the threshold value of 47°C.

Figure 6 represents the time temperature graph for test no 31. Here, the maximum abutment temperature is 63°C. The graph follows the same pattern as for test no 9 but the maximum temperature at abutment level was lower. Channel 3 touches the 47°C line later and for a short period. Channels 4 and 5 do not reach the 47°C line.

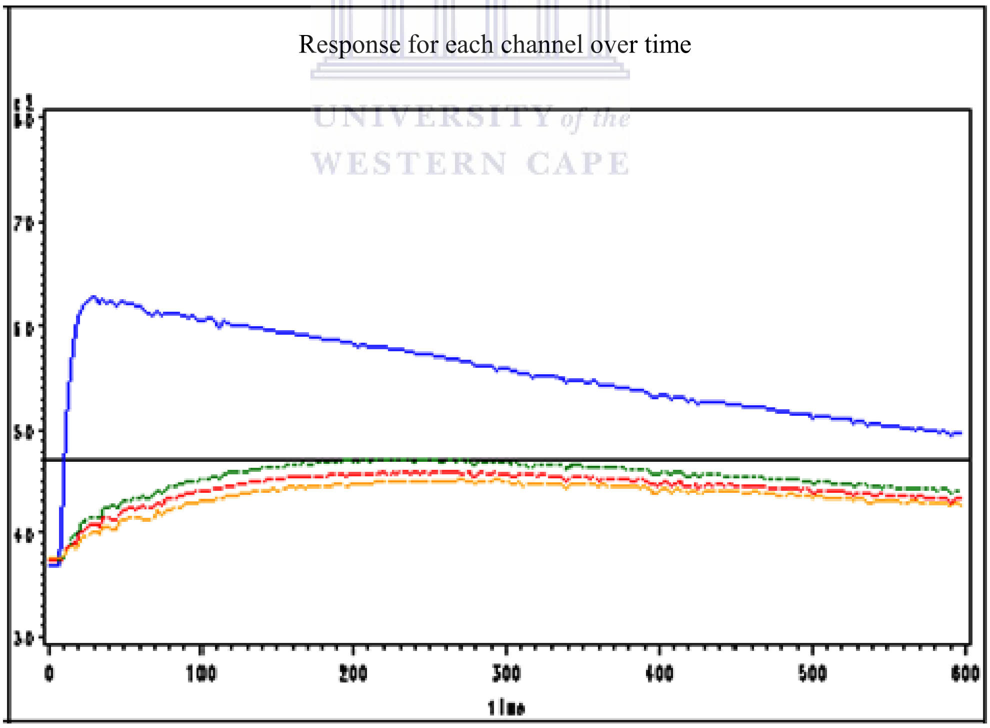

Figure 6: Time temperature graph for test no 31.

3.2 Statistical analysis

Figure 7 represents the correlation of the temperature of the abutment with the temperatures recorded at implant level. As the maximum temperature of the abutment (max2) increases, so does the maximum temperature measured at implant level (max3). There is also a correlation between the increase in highest temperature measured at abutment level and the period that an implant remains at 47^{o}C for 1 minute. The blue circles represent tests where temperatures less than 47^{o}C or 47°C for less than 60 seconds were reached at implant level. The red circles represent tests that reached 47^{o}C for at least 60 seconds at implant level. For temperatures between 52^{o}C - 60^{o}C on max2, the temperature of 47^{o}C for 60 seconds does not occur on implant level (hot2long = 0). But for temperatures above 63^{o}C on max2 there is always a temperature of 47^{o}C for 60 seconds which occurs on implant level (hot2long =1). However, between 61^{o}C-64^{o}C on abutment level, there is a certain threshold temperature that induces 47^{o}C along the implant level for 60 seconds. This area between 61^{o}C-64^{o}C is represented by the 2 vertical dotted lines on the scatter plot.

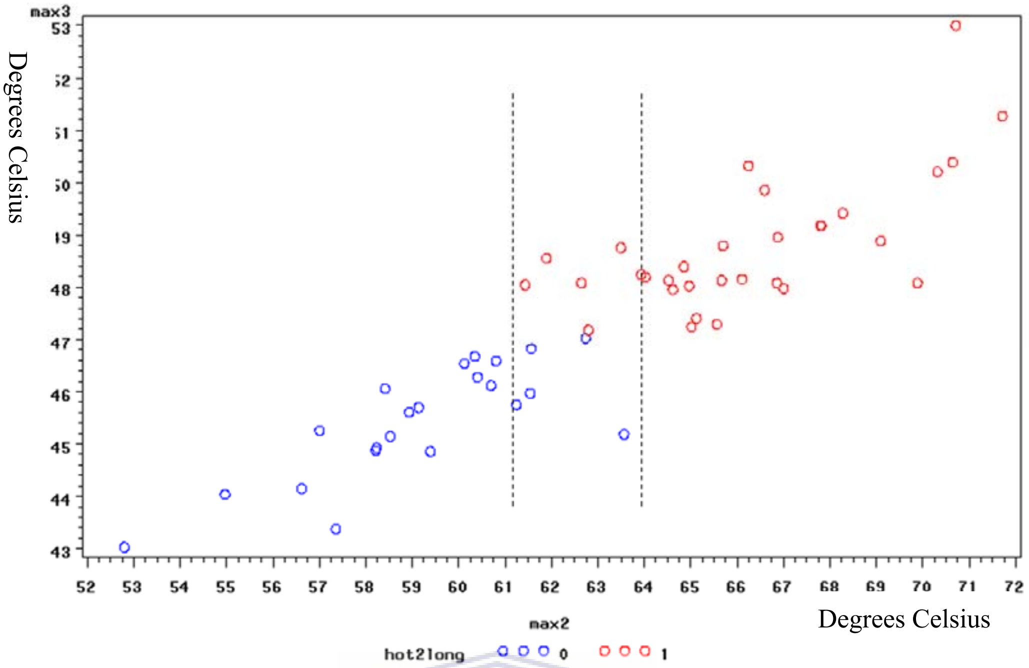

Figure 7: Scatter plot correlating abutment temperatures with implant level temperatures

max2 = maximal abutment temperature; max3 = highest temperature at 1mm below implant collar; hot2long (blue) = temperature less than or at 47°C for less than 60 seconds; hot2long (red) = temperature at or above 47°C for 60 seconds or longer.

The relationship between the maximum temperatures measured at abutment level and the time period that the implant is below, at, or above the critical value of 47ºC for each test is represented by figure 8. Tests that recorded a time period of at least 60 seconds at a temperature of at least 47ºC at implant level are represented by red dots (n= 30). Tests that reached 47ºC for less than 60 seconds or that did not reach 47ºC at all are represented by blue dots (n= 23). The area between the dotted lines indicates a transition area (between 61°C and 64°C) were abutment temperatures might or might not induce the critical threshold value of 47ºC for at least 1 min at implant level.

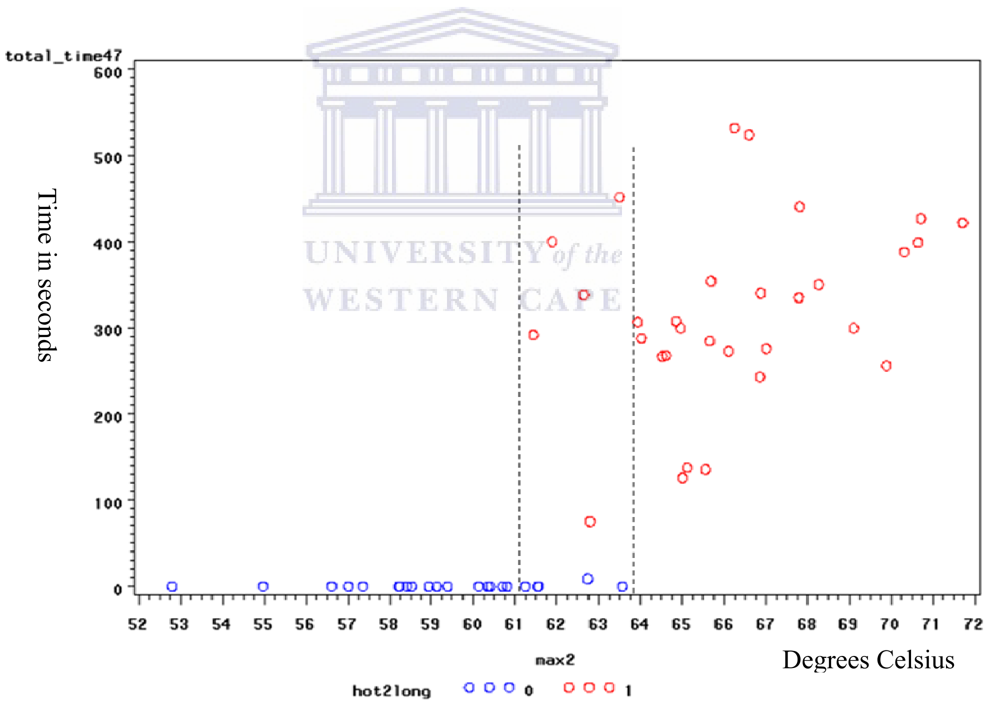

Figure 8: Scatter plot correlating maximum abutment temperature with increased temperature periods at implant level.

max2 = maximum abutment temperature; total_time47 = the length of time that the implant temperature was at or higher than 47°C; hot2long (blue) = temperature at or less than 47°C for less than 60seconds at implant level; hot2long (red) = temperature at or above 47°C for 60 seconds or longer at implant level.

Figure 9 represents the relationship between those tests where 47°C was reached for at least 60 seconds at implant level and the time it took to reach that temperature from the time that the maximum temperature at abutment level was registered. From the scatter plot it can be seen that there is a tendency for higher abutment temperatures (max2) to reach the threshold 47°C for 60 seconds at implant level sooner (time2_47). For lower abutment temperatures, it takes a longer time to reach 47°C at implant level.

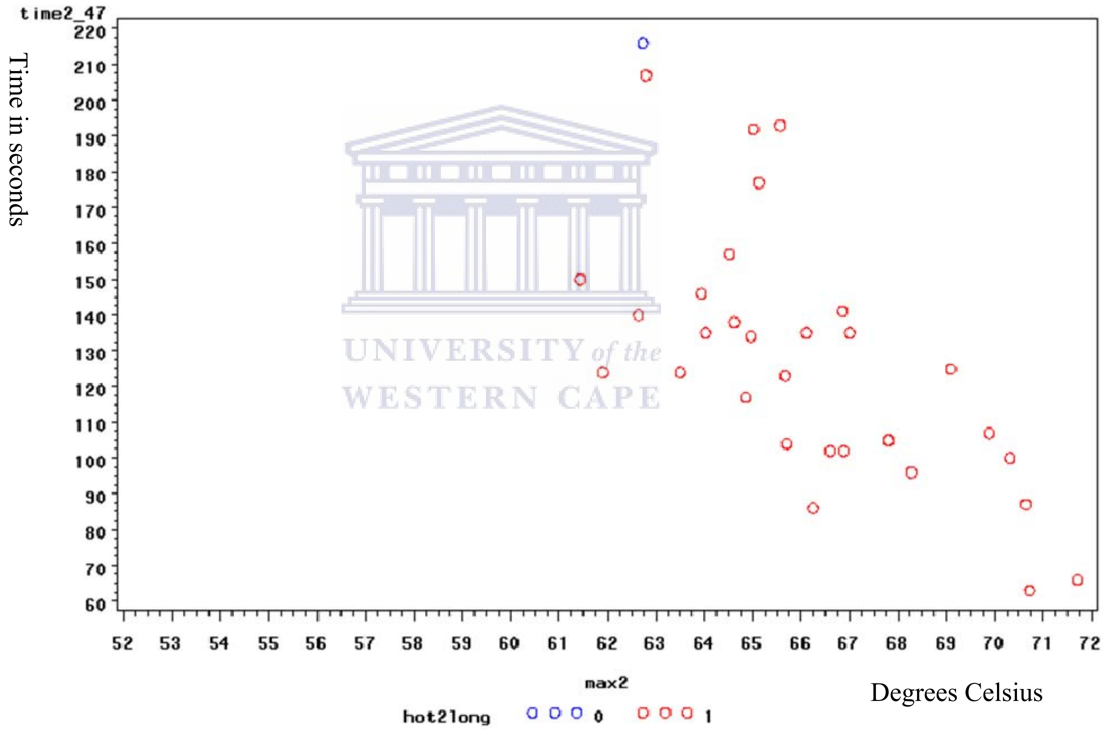

Figure 9: Scatter plot correlating time to reach 47°C at implant level and maximum abutment temperature.

max2 = maximal abutment temperature; max3 = maximal temperature at 1mm below collar of implant; hot2long (blue) = a temperature at or less than 47°C for less than 60seconds; hot2long red = temperature at or above 47°C for 60 seconds or longer; time2_47 = the time taken from max2 to reach 47°C on channel 3.

The estimated effective dose 50 (ED50) is 62.3°C [95% confidence interval estimate (61.5°C, 63.1°C)]. That is, for a maximum temperature in channel 2 of 62.3°C, there is a 50-50 chance that the temperature in channel 3 will exceed 47°C for at least 60 seconds. Although there is some uncertainty in the value of 62.3°C, we can be quite confident that the ED50 is in the range of 61.5°C and 63.1°C. (Figure 10).

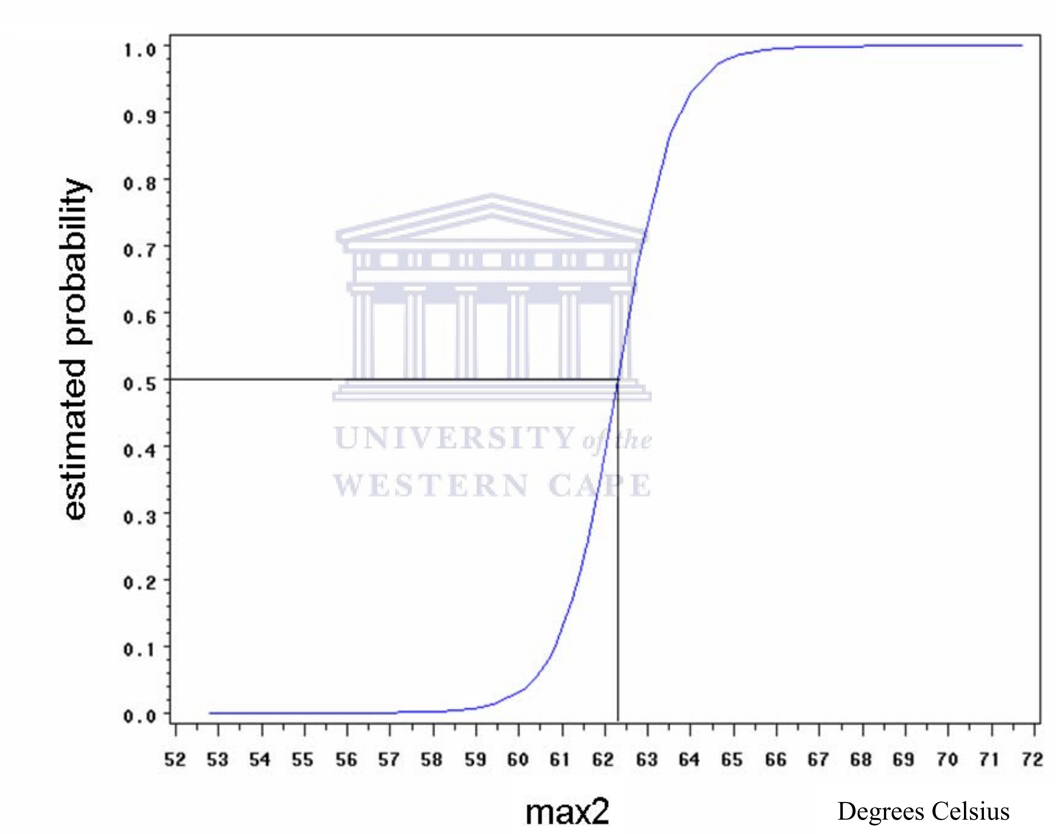

Figure 10: Estimated effective dose 50 and 95% confidence interval.

4. Discussion and conclusion

4.1 Discussion of results

This study looked at temperature changes along the surface of a dental implant following the application of warm water to its abutment. It looked at abutment temperatures responsible for reaching critical temperature threshold values at implant level, if at all.

The answers to the null-hypotheses are as follows:

d) The surface temperature of an implant *is* influenced by the temperature of its abutment.

e) There *is* a delay between temperature rise of the abutment and temperature rise at implant level.

f) A temperature of 47^{o}C for at least 1 minute *can* be reached at implant level.

From the 200 tests that were run, only 53 tests were used in the data analysis. The other 147 tests could not be used because data streaming from the data logger to computer stopped prematurely due to capacity limitations of the equipment. Due to budget constraints, the equipment could not be replaced for this experiment.

The settings for the temperature recording were 1 temperature recording at least every 3 seconds for a duration of 600 seconds for each channel. Some tests were performed at a higher sampling rate, i.e. 1 reading per second or 1 reading every 2 seconds. These sampling rates could give a maximum sampling number (n) of 600 and 300 respectively. However, due to computer limitations, this number of data could not be assimilated and resulted in a lower number of total samples (column n, figure 4).

As can be seen from figure 4, 13 tests did not reach the expected 200 readings (column n). However, the tests ran long enough for the implant temperature to remain at the critical threshold temperature of 47ºC for 1 minute or longer (test no 24) or never reached 47ºC (the remaining 12 tests) and it was decided not to remove them from the database. They were still valuable in determining the value for ED50.

Some tests stopped recording data before the temperature at implant level dropped below 47ºC. In those cases, the times would be said to be truncated. Mean values of the total_time47 are therefore biased downwards. There were no tests where the truncation occurred before 60 seconds. Hence the main variable, hot2long, is not affected by the truncation. (Refer to test 24 in figure 4, page 25).

The rejection of the first null-hypothesis can be explained by referring to figure 7. The maximum temperatures at abutment (max2) and at implant level (max3) were used for this analysis. From the graph it can be seen that as max2 increases, there is a clear tendency for the max3 values to also increase. From the same figure, it can be seen that for higher abutment temperatures, the chance to reach the threshold value of 47ºC for 1 minute also increases (red dots on the graph). There is an intermediate zone, where some abutment temperatures cause a threshold scenario at implant level, others don't.

From figures 5 and 6 it may be noticed that a sudden increase in abutment temperature caused an increase of the temperature of the implant, albeit with a delay. The implant never reaches the same temperature as the abutment. With time, the temperature values of abutment and implant tend to move towards the same value, suggesting a continuous reciprocal effect of abutment and implant temperature.

The delay in temperature rise between abutment and implant can also be assessed by analysing the variables max2 related to time2_47 as shown in figure 9. In other words, how long does it take to reach 47^{o}C in the cases where that temperature is maintained for at least 60 seconds? This question can only be addressed for the abutment temperatures obtained in this study, the highest of which was 71.72^{o}C. For temperatures higher than these (but perhaps not tolerable for human consumption), the time to reach 47^{o}C would be shorter than what we observed. There is a tendency for higher abutment temperatures to reach the threshold 47^{o}C for 60 seconds at implant level sooner. For lower abutment temperatures, the delay to reach 47^{o}C at implant level is longer. Therefore, the second null-hypothesis is rejected.

The shortest observed time to reach 47°C was 63 seconds. This was for test no 7 with a max2 of 70.72°C, which was the second highest max2 in the test series. The longest delay in reaching 47^{o}C for 60 seconds at implant level was 216 seconds (test 31) with a max2 of 62.74ºC. Test 31 was the third 'coolest' test of the 31 tests reaching the threshold value at implant level. The time delay of between *63 and 216 seconds* in my real implant model was considerably longer than the values obtained by Wong *et al.* (2001) in their simulated computer model. They calculated that a temperature of 47^{o}C was reached after a time interval of *1 second* at distances of 1.29mm, 3.45mm and 4.54mm along an implant body after temperature pulses of 50^{o}C, 60^{o}C, and 70^{o}C, respectively.

The third null-hypothesis can be rejected by simply looking at the descriptive data in figure 4. Indeed, under the existing conditions, 31 tests reached the threshold value of 47^{o}C for 60 seconds at implant level.

Warm water was chosen to simulate the effect of hot beverages such as coffee, tea or soup. The temperature range for the tests was chosen based on temperatures recorded in the mouth in previous studies. Surface temperature of intra-oral structures ranging between 0^{o}C – 67^{o}C have been measured (Wong *et al.*, 2001). Others showed that the temperature produced intra-orally during hot water consumption may reach 67^{o}C (Palmer *et al.*, 1992) and even 77^{o}C (Barclay *et al.*, 2005). The established maximum temperature values measured intra-orally were 76.3^{o}C for hot beverages and 53.6^{o}C for hot foods (Feuerstein *et al.*, 2009). However, it must also be noted that the highest tolerable temperature is subjective and varies considerably among the population (Palmer *et al.*, 1992), and is probably affected by factors such as degree of keratinisation of the oral mucosa and age. The temperature of a test was determined as the highest temperature recorded at abutment level (max2). The temperature range for this experiment was from 52.80ºC to 71.20ºC. This range is within the range of temperatures that have been measured in the mouth in these previous studies.

After foods or liquids of extreme temperatures are ingested, oral tissues and saliva tend to return those foods and oral structures to normal oral temperature (Palmer *et al.*, 1992). In this experiment, the heat source was not removed. Instead, it was allowed to cool down while it remained in the upper chamber of the experimental model until the end of the test run. This would represent a "sip" of hot liquid without swallowing the mouthful of liquid. This would not simulate the normal process of consuming warm liquid. Instead it would represent a more extreme situation of a person keeping warm liquid in the mouth for a prolonged period of time. The results of this study may therefore represent higher temperature values along the dental implant than would be observed in the clinical environment.

However, the purpose of this experiment was to assess if temperature changes do occur along the surface of the implant, and to establish lower and upper limits at which certain detrimental threshold values are reached or not i.e. 47^{o}C for 60 seconds. Under the conditions of my study, these temperature/time threshold values were indeed reached. The study can now be refined to better simulate the real process of consuming warm liquids by means of applying an interrupted heat source and to study its cumulative effect along the implant. This is an area for future research.

In evaluating the threshold values, the time-temperature ratio is important. A temperature of 47^{o}C for the duration of 60 seconds was found to affect osteoblast activity by causing necrosis (Wong *et al.*, 2001; Eriksson and Albrektsson, 1983). This time/temperature threshold was used in this study, because it appears to be the most popular benchmark in research studies as well as for clinical practice. Another example of time/temperature ratio is the one mentioned in publications by Misch (1999) and Duyck and Naert (1998): bone necrosis occurs when a temperature of 40^{o}C is applied for 7 minutes. My study only compared the results in terms of the 47ºC for 1 minute threshold value. The same analysis can be repeated for all the other values reported in the literature. This may be performed as part of a larger and more comprehensive study.

It is important to bear in mind that these threshold values were established mainly by means of experimental animal tissue studies (Eriksson and Albrektsson, 1983). Human tissue may not necessarily react in the same manner as animal tissue. Due to the absence of similar data for human tissue, these values have been used merely as standards in scientific literature.

Figure 10 calculated the critical abutment temperature where there is a 50% chance that 47^{o}C for 60 seconds will occur at the first millimeter (channel 3) at implant level. Under the test conditions, this threshold temperature is determined to be 62.3^{o}C. My study also showed that for a maximum abutment temperature below 61^{o}C, and without removing the heat source, the threshold value of 47ºC for 60 seconds is *never* reached at implant level. For a maximum abutment temperature of 64 °C and higher, the threshold value of 47°C for 60 seconds is *always* reached at channel one of the dental implant body.

Wong *et al.* (2001), using a computer model, calculated that a temperature front of 47°C could develop at a distance of 3 to 4.5 mm along the implant body during heating of the dental implant head to 60°C and 70°C. It was evident from my experiment that the temperature of 47°C is easily obtained at 1mm below abutment/implant interface level as the temperature increased beyond the threshold of 62.3°C. Following Wong and co-workers' argument of a temperature front originating from the heat source, this may provide an explanation for the clinical observation of *crestal* bone loss around dental implants: the crestal bone, being closest to the heat source, is the most "thermocycled" part of the peri-implant bone. This may provide an additional stress factor to crestal bone pathology (Wong *et al.*, 2001).

The temperature of 42°C induced transient changes in osteoblasts (Li *et al.*, 1999). This temperature is easily attained on all channels on the implant body. At 42°C there is disruption of the actin filaments, and membrane ruffling at the cell periphery. The degree of disruption increased with temperature (Li *et al.*, 1999).

At a temperature above 45°C, as exemplified by that at 48°C, induces irreversible responses such as necrosis and apoptosis (Li *et al.*, 1999). The duration of heat shock is also important, since a prolonged elevation in temperature above 44°C has been correlated clinically with an increase in implant failure (Calder *et al.*, 1995). Osteoblasts treated at 45°C could recover without an increase in the rate of apoptosis, but those treated at 48°C showed an increase of the apoptosis rate to 10%, suggesting that the protective mechanism was unable to repair the damage at 48°C or suppress the apoptotic program in some of the cells (Li *et al*., 1999). In addition, Li *et al.* (1999) mention that necrotic tissue may provide conditions favourable for bacterial infection.

As discussed previously in chapter 1, page 12 and 13, it is important not to exceed the temperature threshold of osteoblast cell types as cell damage can occur.

There was a delay in the recording of maximum temperatures at abutment level and at implant level. Besides the thermoconductive properties of the metal, a possible explanation for this could be the air space between the abutment and implant which slows down the temperature conduction. Another reason for delayed and lower temperature values measured at implant level may be due to heat transfer to the surrounding environment. Future research can focus on different implant designs and dimensions, as well as different implant/abutment connections.

The hot water was not removed and was allowed to cool off within the upper chamber representing the oral cavity. The temperatures at abutment and implant levels tended to move closer together over time. It would be interesting to study the cumulative effect of an intermittent heat source application on the different levels of the implant body. A cumulative effect might exist because this study found a delay in reaching the maximum temperature at implant level. Therefore, a lag period during cooling off might also be expected.

The volume of the heat source was pegged at 30ml to resemble the volume of a sip of hot water. A 50 ml syringe (1ml scale) was used to measure the volume of hot water as well as to squeeze the water into the upper chamber of the experimental model via a rubber tube. Air entrapment in the tube might have influenced the volume of water that ended up in the upper chamber. This may have influenced the rate at which energy is delivered to and maintained in the upper chamber and the eventual maximum temperature of the abutment.

The continuous exposure to the heat source, as was simulated in this study, probably more closely resembles the presence of heat during the exothermic polymerization reaction of some materials used for the manufacturing of direct provisional restorations or for making impressions. Further research could be performed, using this experimental model, to study the influence of these materials on implant temperature. Only 2 publications were found investigating this type of scenario: in 2000, Ormianer *et al.* used thermocouples to investigate heat generation at the implant surface due to the exothermic setting reaction of autopolymerizing acrylic resins applied to an abutment connected to an implant *in vitro.* A maximum temperature increase of 6^{o}C at the cervical part of the implant was recorded. With the base temperature of the implant at 37^{o}C this meant a temperature of 43^{o}C degrees at the implant surface. Hyperaemia and increased capillary filtration can occur at 41^{o}C to 43^{o}C (Eriksson *et al.*, 1982, 1984; Eriksson and Albrektsson 1983).

The second one is by Nissan *et al.* (2006): they investigated temperature changes at the cervical and apical part of an implant surface, caused by impression plaster. Temperature changes in the range of $2^{o}C$ to $3^{o}C$ were seen, which were considered clinically insignificant.

For obvious reasons, all the studies published so far on heat transmission along the surface of dental implants used *in vitro* models with the exception of 1 study: a 2009 publication by Ormianer *et al.* used an *in vivo* model where thermocouples were placed *inside* successfully integrated implants. However, the limitations of this study were the small sample size (a total of 8 implants) and the fact that the temperature was measured inside the implant and not at the surface where it contacts the surrounding tissues.

4.2. Problems encountered

4.2.1. *Placing the thermocouples on the implant*

There were several ways to do this. Initially it was decided to microscopically groove the implant at every millimetre but this would take too much of time, expertise and raise cost. An alternative was to use an epoxy that would secure the thermocouple to the implant body but still allowing conductivity of heat. Pratley steel® was chosen.

4.2.2. *The computer used for the experiment*

A P4 Core 2 Duo® with 2 gigabyte of ram was used. This machine did not work totally satisfactorily. The transmission rate from the thermocouples needs a machine that can process this live information very quickly. For future tests, a P4 Quad core® with a minimum of 4 gigabyte of ram should be used.

4.2.3 *The calibration of the device before each test*

Before each test was conducted the entire test model was calibrated. All eight thermocouples had to be at body temperature. The estimated time per calibration was about 20 minutes. The duration to complete the experiment therefore became very long.

4.2.4 *The environmental chamber*

The experiment was first performed at room temperature. However, the influence of the small environmental changes in the air-conditioned office was too large to effectively calibrate the model before the start of each test. Therefore, it was decided to build a temperature controlled chamber and to place the model in the chamber. For this study, a temperature of 32ºC in the chamber created the correct environmental temperature to allow effective calibration of the implant model between each test.

4.2.5 Leakage of water and the influence of water on the readings

During testing, we observed that the reading had become unstable. Investigation revealed that the silicone seal covering the implant body was lost. Once it was repaired, the tests worked normally.

4.2.6 Estimating the temperature of the hot water bath for the desired temperature of the abutment

After many tests an average temperature loss of about 15ºC from the temperature of the heated water to the temperature of the abutment was established. The reasons for this could be the ambient temperature, the time taken from the drawing of the water and the insertion into the upper chamber. These variables were slightly different for each test.

4.3 Conclusions

Within the limitations of this *in vitro* study, results showed that:

- The temperature of the abutment has an influence on the temperature of the implant surface, albeit with a time delay.
- The threshold value of 47ºC for 1 minute can be reached at the implant surface.

- The critical abutment temperature for reaching this threshold value with a 50% chance is established at 62.3ºC.

Scientific evidence from prospective and controlled clinical studies on this topic is not available. When it comes to extrapolating results into clinical practice, results from *in vitro* studies should be approached with caution.

However, the fact that threshold values could be exceeded in experimental models should warn clinicians about the potential risks evident when hot beverages are consumed by patients with dental implants.

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Addendum

Example of a complete time/temperature database for test 1

Time Seconds	Channel 1 °C	Channel 2 °C	Channel : °C	Channe °C	Channel °C	Channel °C	Channel °C	Channel °C	Cold Jun °C
0	36.13	36.71	37.51	37.64	37.75	38.04	37.93	38.02	26.19
1	36.13	36.71	37.51	37.66	37.73	38	37.93	38.04	26.19
2	36.13	36.71	37.51	37.66	37.73	38	37.93	38.04	26.19
3	36.15	36.77	37.62	37.62	37.82	38.08	38	38.13	26.19
4	36.15	36.8	37.55	37.66	37.75	37.97	37.91	38	26.19
5	36.17	36.77	37.62	37.68	37.77	37.93	37.88	38.11	26.19
6	36.17	36.77	37.62	37.68	37.77	37.93	37.88	38.11	26.19
7	36.17	36.8	37.57	37.66	37.77	38.02	37.93	38.08	26.19
8	36.15	36.77	37.62	37.66	37.82	37.97	38	38.08	26.19
9	36.13	36.75	37.55	37.75	37.8	38	38.02	38.11	26.18
10	36.13	36.75	37.55	37.75	37.8	38	38.02	38.11	26.18
11	36.17	36.82	37.55	37.73	37.82	38.06	37.97	38.06	26.19
12	36.15	36.77	37.53	37.71	37.77	38.02	37.93	37.97	26.18
13	36.02	36.77	37.55	37.66	37.77	38.04	37.91	38.04	26.18
14	36.02	36.77	37.55	37.66	37.77	38.04	37.91	38.04	26.18
15	36.04	36.84	37.62	37.71	37.82	38	37.95	38.02	26.18
16	35.97	36.77	37.57	37.71	37.8	37.86	37.91	38.02	26.18
17	35.82	36.75	37.53	37.66	37.73	37.95	37.86	37.88	26.18
18	35.82	36.75	37.53	37.66	37.73	37.95	37.86	37.88	26.18
19	35.8	36.77	37.53	37.68	37.75	37.93	37.88	37.86	26.18
20	35.75	36.8	37.57	37.66	37.68	37.97	37.84	37.8	26.18
21	35.6	36.66	37.48	37.57	37.73	37.86	37.77	37.84	26.17
22	35.6	36.66	37.48	37.57	37.73	37.86	37.77	37.84	26.17
23	35.57	36.75	37.48	37.57	37.73	37.84	37.73	37.71	26.17
24	35.51	36.75	37.48	37.57	37.71	37.77	37.71	37.75	26.17
25	35.42	36.73	37.48	37.6	37.62	37.86	37.77	37.71	26.17
26	35.42	36.73	37.48	37.6	37.62	37.86	37.77	37.71	26.17
27	35.35	36.68	37.48	37.64	37.64	37.8	37.73	37.71	26.16
28	35.31	36.68	37.51	37.55	37.64	37.75	37.68	37.66	26.16
29	35.26	36.68	37.4	37.55	37.66	37.68	37.66	37.68	26.17
30	35.26	36.68	37.4	37.55	37.66	37.68	37.66	37.68	26.17
31	35.22	36.68	37.44	37.55	37.57	37.71	37.64	37.55	26.17
32	35.13	36.64	37.42	37.55	37.6	37.71	37.66	37.57	26.17
33	35.06	36.62	37.37	37.46	37.48	37.71	37.55	37.46	26.17
34	35.06	36.62	37.37	37.46	37.48	37.71	37.55	37.46	26.17
35	35.11	36.66	37.44	37.51	37.62	37.68	37.57	37.57	26.18
36	35.08	36.66	37.44	37.55	37.55	37.66	37.57	37.55	26.18
37	35.08	36.66	37.44	37.55	37.55	37.66	37.57	37.55	26.18
38	35	36.62	37.37	37.53	37.51	37.62	37.55	37.57	26.19
39	34.95	36.6	37.42	37.44	37.48	37.62	37.53	37.44	26.18
40	34.95	36.62	37.46	37.46	37.44	37.62	37.48	37.46	26.18
41	34.95	36.62	37.46	37.46	37.44	37.62	37.48	37.46	26.18
42	34.88	36.6	37.4	37.42	37.42	37.64	37.48	37.42	26.18
43	34.86	36.62	37.4	37.44	37.57	37.53	37.44	37.44	26.18
44	34.77	36.53	37.35	37.4	37.48	37.51	37.4	37.42	26.18
45	34.77	36.53	37.35	37.4	37.48	37.51	37.4	37.42	26.18
46	34.82	36.6	37.37	37.44	37.51	37.53	37.44	37.44	26.19
47	34.75	36.53	37.26	37.37	37.46	37.48	37.35	37.35	26.19
48	34.71	36.48	37.28	37.42	37.4	37.46	37.4	37.35	26.19

49	34.71	36.48	37.28	37.42	37.4	37.46	37.4	37.35	26.19
50	34.68	36.51	37.35	37.37	37.42	37.48	37.37	37.35	26.2
51	34.66	36.51	37.31	37.35	37.42	37.48	37.4	37.4	26.2
52	34.64	36.48	37.31	37.33	37.37	37.51	37.35	37.31	26.21
53	34.64	36.48	37.31	37.33	37.37	37.51	37.35	37.31	26.21
54	34.66	36.46	37.28	37.4	37.44	37.46	37.44	37.33	26.21
55	34.62	36.46	37.33	37.35	37.37	37.46	37.42	37.31	26.21
56	34.57	36.44	37.28	37.33	37.33	37.44	37.31	37.24	26.21
57	34.57	36.44	37.28	37.33	37.33	37.44	37.31	37.24	26.21
58	34.6	36.35	37.22	37.26	37.31	37.4	37.28	37.26	26.22
59	39	40.08	37.37	37.35	37.37	37.42	37.37	37.26	26.22
60	56.73	47.74	37.71	37.57	37.4	37.42	37.28	37.26	26.22
61	56.73	47.74	37.71	37.57	37.4	37.42	37.28	37.26	26.22
62	63.09	53.28	38.22	37.8	37.53	37.37	37.33	37.26	26.22
63	65.92	57.41	38.8	38.22	37.8	37.44	37.37	37.24	26.23
64	67.76	60.35	39.26	38.55	38.04	37.6	37.42	37.26	26.23
65	67.76	60.35	39.26	38.55	38.04	37.6	37.42	37.26	26.23
66	69.12	62.47	39.68	38.86	38.13	37.62	37.51	37.33	26.23
67	70.37	64.12	40.08	39.08	38.31	37.77	37.57	37.4	26.23
68	71.04	65.32	40.46	39.4	38.57	37.84	37.64	37.44	26.24
69	71.04	65.32	40.46	39.4	38.57	37.84	37.64	37.44	26.24
70	71.35	66.22	40.79	39.62	38.68	38	37.73	37.46	26.24
71	71.72	66.84	40.99	39.86	38.86	38.06	37.75	37.46	26.23
72	71.72	66.84	40.99	39.86	38.86	38.06	37.75	37.46	26.23
73	72	67.25	41.23	40.04	39.06	38.22	37.88	37.53	26.23
74	72	67.56	41.48	40.24	39.2	38.28	37.95	37.62	26.24
75	71.98	67.67	41.63	40.46	39.31	38.4	38.08	37.71	26.24
76	71.98	67.67	41.63	40.46	39.31	38.4	38.08	37.71	26.24
77	72	67.76	41.92	40.57	39.44	38.55	38.13	37.77	26.23
78	72.03	67.8	42.01	40.7	39.66	38.62	38.26	37.88	26.23
79	72.03	67.8	42.01	40.7	39.66	38.62	38.26	37.88	26.23
80	72	67.76	42.16	40.88	39.77	38.73	38.33	37.95	26.23
81	71.98	67.69	42.32	41.03	39.86	38.88	38.46	37.97	26.23
82	71.98	67.69	42.32	41.03	39.86	38.88	38.46	37.97	26.23
83	71.94	67.67	42.45	41.17	40.08	38.91	38.51	38.11	26.23
84	71.81	67.52	42.58	41.28	40.15	39	38.57	38.15	26.22
85	71.7	67.56	42.76	41.41	40.3	39.22	38.71	38.28	26.23
86	71.7	67.56	42.76	41.41	40.3	39.22	38.71	38.28	26.23
87	71.68	67.39	42.83	41.57	40.33	39.22	38.77	38.33	26.22
88	71.83	67.32	42.94	41.65	40.42	39.26	38.84	38.4	26.22
89	71.83	67.32	42.94	41.65	40.42	39.26	38.84	38.4	26.22
90	71.72	67.23	43.07	41.76	40.53	39.37	38.86	38.37	26.22
91	71.63	67.17	43.16	41.81	40.7	39.51	39.02	38.53	26.21
92	71.63	67.17	43.16	41.81	40.7	39.51	39.02	38.53	26.21
93	71.44	67.06	43.29	41.92	40.73	39.64	39.06	38.55	26.22
94	71.28	66.99	43.29	42.03	40.81	39.62	39.2	38.62	26.22
95	71.28	66.95	43.49	42.07	40.97	39.77	39.26	38.77	26.22
96	71.28	66.95	43.49	42.07	40.97	39.77	39.26	38.77	26.22
97	71.2	66.9	43.6	42.23	41.03	39.91	39.42	38.8	26.22
98	71.02	66.79	43.65	42.36	41.15	40	39.37	38.88	26.22
99	71.02	66.79	43.65	42.36	41.15	40	39.37	38.88	26.22
100	71.02	66.77	43.71	42.47	41.28	40.06	39.51	38.97	26.22

101	70.98	66.66	43.89	42.5	41.32	40.15	39.62	38.95	26.21
102	70.98	66.66	43.89	42.5	41.32	40.15	39.62	38.95	26.21
103	70.78	66.62	43.93	42.56	41.32	40.17	39.62	39.06	26.22
104	70.39	66.55	44.02	42.63	41.48	40.22	39.68	39.13	26.22
105	70.32	66.46	44.13	42.78	41.5	40.33	39.82	39.2	26.21
106	70.32	66.46	44.13	42.78	41.5	40.33	39.82	39.2	26.21
107	70.45	66.44	44.22	42.83	41.59	40.44	39.88	39.26	26.21
108	70.43	66.35	44.33	42.92	41.74	40.53	39.93	39.28	26.22
109	70.37	66.29	44.38	43	41.81	40.59	40	39.37	26.22
110	70.37	66.29	44.38	43	41.81	40.59	40	39.37	26.22
111	70.3	66.25	44.49	43.05	41.92	40.7	40.06	39.44	26.22
112	70.21	66.18	44.55	43.16	41.94	40.73	40.13	39.4	26.22
113	70.08	66.14	44.64	43.18	41.99	40.73	40.17	39.48	26.23
114	70.08	66.14	44.64	43.18	41.99	40.73	40.17	39.48	26.23
115	70.1	66.14	44.71	43.38	42.12	40.88	40.28	39.64	26.23
116	69.91	66.09	44.82	43.36	42.23	40.95	40.33	39.68	26.23
117	69.67	65.98	44.84	43.45	42.19	41.01	40.44	39.73	26.23
118	69.67	65.98	44.84	43.45	42.19	41.01	40.44	39.73	26.23
119	69.51	65.92	44.95	43.51	42.34	41.01	40.44	39.77	26.23
120	69.42	65.89	44.93	43.56	42.38	41.1	40.5	39.8	26.23
121	69.42	65.89	44.93	43.56	42.38	41.1	40.5	39.8	26.23
122	69.29	65.85	45.08	43.62	42.43	41.19	40.59	39.82	26.23
123	69.23	65.81	45.17	43.78	42.54	41.21	40.64	39.93	26.23
124	69.1	65.74	45.26	43.8	42.56	41.3	40.7	39.95	26.23
125	69.1	65.74	45.26	43.8	42.56	41.3	40.7	39.95	26.23
126	68.92	65.67	45.3	43.82	42.65	41.39	40.75	39.95	26.23
127	68.92	65.61	45.37	43.91	42.72	41.46	40.77	40.11	26.23
128	68.96	65.57	45.48	44	42.76	41.48	40.88	40.15	26.23
129	68.96	65.57	45.48	44	42.76	41.48	40.88	40.15	26.23
130	68.9	65.5	45.5	44	42.8	41.54	40.88	40.17	26.23
131	68.77	65.48	45.57	44.09	42.89	41.59	40.97	40.17	26.24
132	68.66	65.43	45.68	44.15	42.89	41.61	40.99	40.24	26.24
133	68.66	65.43	45.68	44.15	42.89	41.61	40.99	40.24	26.24
134	68.55	65.37	45.68	44.24	43	41.7	41.01	40.28	26.24
135	68.59	65.3	45.75	44.18	43.07	41.79	41.08	40.35	26.25
136	68.59	65.3	45.75	44.18	43.07	41.79	41.08	40.35	26.25
137	68.48	65.28	45.84	44.35	43.11	41.83	41.1	40.39	26.25
138	68.28	65.21	45.92	44.46	43.16	41.94	41.15	40.44	26.25
139	68.28	65.21	45.92	44.46	43.16	41.94	41.15	40.44	26.25
140	68.13	65.17	45.99	44.51	43.18	41.96	41.26	40.48	26.25
141	68.02	65.17	46.1	44.57	43.36	42.03	41.26	40.57	26.25
142	67.93	65.06	46.17	44.62	43.31	42.12	41.41	40.57	26.25
143	67.93	65.06	46.17	44.62	43.31	42.12	41.41	40.57	26.25
144	67.85	65.06	46.21	44.64	43.49	42.19	41.39	40.64	26.26
145	67.85	65	46.21	44.75	43.49	42.16	41.43	40.68	26.25
146	67.78	64.93	46.37	44.75	43.51	42.19	41.48	40.73	26.26
147	67.78	64.93	46.37	44.75	43.51	42.19	41.48	40.73	26.26
148	67.69	64.95	46.37	44.84	43.58	42.36	41.59	40.81	26.25
149	67.65	64.93	46.46	44.88	43.62	42.38	41.54	40.77	26.26
150	67.63	64.86	46.48	44.93	43.71	42.41	41.72	40.86	26.26
151	67.63	64.86	46.48	44.93	43.71	42.41	41.72	40.86	26.26
152	67.54	64.8	46.54	45.02	43.8	42.5	41.76	40.92	26.26

153	67.52	64.75	46.59	45.02	43.78	42.54	41.76	41.06	26.26
154	67.39	64.71	46.65	45.08	43.84	42.54	41.76	41.01	26.26
155	67.39	64.71	46.65	45.08	43.84	42.54	41.76	41.01	26.26
156	67.34	64.67	46.7	45.13	43.93	42.58	41.83	41.03	26.26
157	67.36	64.64	46.76	45.19	43.96	42.67	41.92	41.15	26.27
158	67.34	64.62	46.83	45.24	44.04	42.72	41.92	41.17	26.27
159	67.34	64.62	46.83	45.24	44.04	42.72	41.92	41.17	26.27
160	67.28	64.58	46.81	45.28	44.11	42.78	42.01	41.23	26.27
161	67.21	64.53	46.9	45.35	44.18	42.8	42.07	41.3	26.28
162	67.14	64.49	46.99	45.39	44.13	42.89	42.12	41.3	26.28
163	67.14	64.49	46.99	45.39	44.13	42.89	42.12	41.3	26.28
164	67.03	64.47	47.01	45.48	44.31	42.87	42.12	41.34	26.28
165	66.88	64.45	47.03	45.48	44.24	42.94	42.23	41.34	26.28
166	66.75	64.4	47.1	45.59	44.4	43.05	42.27	41.43	26.29
167	66.75	64.4	47.1	45.59	44.4	43.05	42.27	41.43	26.29
168	66.66	64.36	47.12	45.53	44.26	43.05	42.25	41.41	26.29
169	66.62	64.32	47.19	45.61	44.4	43.11	42.34	41.46	26.28
170	66.62	64.32	47.19	45.61	44.4	43.11	42.34	41.46	26.28
171	66.51	64.27	47.27	45.68	44.4	43.11	42.36	41.54	26.28
172	66.35	64.21	47.25	45.7	44.44	43.2	42.41	41.5	26.28
173	66.27	64.14	47.27	45.77	44.57	43.18	42.41	41.52	26.29
174	66.27	64.14	47.27	45.77	44.57	43.18	42.41	41.52	26.29
175	66.16	64.14	47.34	45.79	44.55	43.27	42.54	41.59	26.28
176	66.14	64.12	47.43	45.88	44.66	43.34	42.56	41.65	26.29
177	66.14	64.12	47.43	45.88	44.66	43.34	42.56	41.65	26.29
178	66.07	64.05	47.47	45.9	44.69	43.31	42.52	41.74	26.29
179	66.07	64.07	47.5	45.95	44.73	43.4	42.58	41.76	26.29
180	66.07	64.07	47.5	45.95	44.73	43.4	42.58	41.76	26.29
181	65.98	64.01	47.61	45.99	44.82	43.53	42.65	41.79	26.3
182	65.81	63.92	47.63	46.08	44.82	43.51	42.67	41.83	26.29
183	65.87	63.88	47.65	46.06	44.86	43.53	42.69	41.85	26.29
184	65.87	63.88	47.65	46.06	44.86	43.53	42.69	41.85	26.29
185	65.87	63.9	47.72	46.15	44.97	43.69	42.85	41.92	26.29
186	65.87	63.83	47.67	46.17	44.95	43.67	42.74	41.92	26.29
187	65.87	63.83	47.67	46.17	44.95	43.67	42.74	41.92	26.29
188	65.76	63.81	47.74	46.21	45.04	43.67	42.94	42.14	26.29
189	65.7	63.77	47.87	46.17	45.04	43.8	42.94	42.12	26.29
190	65.65	63.75	47.85	46.21	45.06	43.78	42.92	42.1	26.29
191	65.65	63.75	47.85	46.21	45.06	43.78	42.92	42.1	26.29
192	65.61	63.7	47.85	46.34	45.08	43.8	42.98	42.16	26.29
193	65.54	63.7	47.92	46.37	45.15	43.84	43.07	42.16	26.29
194	65.5	63.66	47.98	46.37	45.15	43.89	43.03	42.14	26.29
195	65.5	63.66	47.98	46.37	45.15	43.89	43.03	42.14	26.29
196	65.5	63.59	47.94	46.34	45.17	43.89	43.05	42.21	26.3
197	65.5	63.59	48.09	46.41	45.28	43.96	43.11	42.23	26.3
198	65.43	63.55	48.07	46.52	45.26	43.98	43.11	42.32	26.3
199	65.43	63.55	48.07	46.52	45.26	43.98	43.11	42.32	26.3
200	65.35	63.5	48.14	46.52	45.33	44.07	43.18	42.34	26.3
201	65.32	63.5	48.11	46.54	45.42	44.09	43.23	42.36	26.31
202	65.21	63.42	48.16	46.61	45.42	44.09	43.29	42.38	26.31
203	65.21	63.42	48.16	46.61	45.42	44.09	43.29	42.38	26.31
204	65.08	63.37	48.16	46.61	45.46	44.18	43.29	42.43	26.31

205	65.02	63.39	48.23	46.68	45.46	44.2	43.27	42.41	26.31
206	65.02	63.39	48.23	46.68	45.46	44.2	43.27	42.41	26.31
207	64.93	63.33	48.25	46.7	45.48	44.22	43.31	42.47	26.31
208	64.82	63.31	48.25	46.76	45.57	44.26	43.34	42.54	26.31
209	64.71	63.28	48.29	46.72	45.53	44.31	43.45	42.58	26.31
210	64.71	63.28	48.29	46.72	45.53	44.31	43.45	42.58	26.31
211	64.71	63.22	48.4	46.74	45.57	44.24	43.42	42.52	26.31
212	64.64	63.2	48.38	46.79	45.57	44.26	43.42	42.56	26.31
213	64.6	63.15	48.36	46.85	45.75	44.35	43.51	42.67	26.31
214	64.6	63.15	48.36	46.85	45.75	44.35	43.51	42.67	26.31
215	64.56	63.13	48.4	46.88	45.66	44.31	43.56	42.63	26.3
216	64.42	63.04	48.45	46.83	45.73	44.44	43.56	42.65	26.3
217	64.42	63.04	48.45	46.83	45.73	44.44	43.56	42.65	26.3
218	64.45	63.04	48.4	46.9	45.7	44.46	43.58	42.72	26.29
219	64.34	63	48.49	46.94	45.75	44.51	43.65	42.72	26.29
220	64.29	62.96	48.51	46.92	45.75	44.51	43.65	42.78	26.29
221	64.29	62.96	48.51	46.92	45.75	44.51	43.65	42.78	26.29
222	64.16	62.89	48.47	46.85	45.75	44.49	43.62	42.67	26.29
223	64.1	62.91	48.58	47.03	45.84	44.6	43.71	42.78	26.28
224	64.05	62.85	48.58	46.94	45.81	44.57	43.65	42.8	26.28
225	64.05	62.85	48.58	46.94	45.81	44.57	43.65	42.8	26.28
226	63.99	62.8	48.56	46.99	45.92	44.6	43.73	42.85	26.28
227	64.03	62.74	48.58	47.01	45.86	44.6	43.73	42.85	26.28
228	64.03	62.74	48.58	47.01	45.86	44.6	43.73	42.85	26.28
229	63.99	62.74	48.6	47.05	45.86	44.64	43.76	42.92	26.28
230	63.96	62.69	48.6	47.12	45.84	44.69	43.8	42.89	26.28
231	63.83	62.63	48.65	47.05	45.92	44.69	43.8	42.94	26.28
232	63.83	62.63	48.65	47.05	45.92	44.69	43.8	42.94	26.28
233	63.85	62.63	48.73	47.16	45.99	44.73	43.82	42.92	26.28
234	63.81	62.63	48.69	47.16	46.01	44.8	43.96	42.98	26.29
235	63.72	62.54	48.73	47.12	46.03	44.75	43.91	42.96	26.29
236	63.72	62.54	48.73	47.12	46.03	44.75	43.91	42.96	26.29
237	63.64	62.54	48.76	47.23	46.06	44.8	43.93	42.96	26.29
238	63.57	62.47	48.8	47.21	46.08	44.84	43.91	43	26.29
239	63.57	62.47	48.8	47.21	46.08	44.84	43.91	43	26.29
240	63.46	62.47	48.76	47.21	46.06	44.77	43.98	43.03	26.29
241	63.39	62.39	48.8	47.23	46.12	44.93	44	43.09	26.29
242	63.37	62.36	48.8	47.23	46.12	44.86	43.98	43.05	26.29
243	63.37	62.36	48.8	47.23	46.12	44.86	43.98	43.05	26.29
244	63.28	62.36	48.87	47.25	46.19	44.88	44.02	43.14	26.3
245	63.24	62.3	48.84	47.3	46.15	44.93	44.02	43.09	26.29
246	63.15	62.3	48.89	47.36	46.23	44.91	44.09	43.14	26.3
247	63.15	62.3	48.89	47.36	46.23	44.91	44.09	43.14	26.3
248	63.15	62.3	48.91	47.32	46.23	44.93	44.07	43.23	26.3
249	63.13	62.19	48.87	47.38	46.21	45.06	44.18	43.2	26.3
250	63.13	62.19	48.87	47.38	46.21	45.06	44.18	43.2	26.3
251	63.02	62.14	48.91	47.38	46.26	44.97	44.07	43.18	26.3
252	62.96	62.12	48.89	47.38	46.23	45.04	44.11	43.18	26.3
253	62.87	62.08	48.89	47.38	46.23	45.15	44.22	43.27	26.3
254	62.87	62.08	48.89	47.38	46.23	45.15	44.22	43.27	26.3
255	62.85	62.06	49.02	47.32	46.28	45.06	44.15	43.25	26.3
256	62.82	62.01	48.93	47.41	46.3	45.08	44.22	43.25	26.3

257	62.74	61.97	48.98	47.43	46.28	45.08	44.2	43.25	26.3
258	62.74	61.97	48.98	47.43	46.28	45.08	44.2	43.25	26.3
259	62.6	61.92	48.96	47.43	46.34	45.06	44.24	43.34	26.3
260	62.56	61.92	48.93	47.5	46.3	45.13	44.22	43.29	26.3
261	62.56	61.92	48.93	47.5	46.3	45.13	44.22	43.29	26.3
262	62.45	61.79	48.98	47.38	46.39	45.13	44.24	43.29	26.31
263	62.41	61.79	48.98	47.5	46.32	45.17	44.26	43.36	26.3
264	62.3	61.79	49.04	47.5	46.48	45.15	44.33	43.38	26.31
265	62.3	61.79	49.04	47.5	46.48	45.15	44.33	43.38	26.31
266	62.28	61.75	49	47.52	46.37	45.19	44.33	43.36	26.31
267	62.19	61.73	49.09	47.43	46.46	45.22	44.33	43.42	26.31
268	62.17	61.73	49.04	47.58	46.5	45.26	44.4	43.45	26.32
269	62.17	61.73	49.04	47.58	46.5	45.26	44.4	43.45	26.32
270	62.08	61.68	49.11	47.54	46.52	45.19	44.31	43.47	26.32
271	62.1	61.62	49.02	47.56	46.39	45.24	44.4	43.45	26.32
272	62.03	61.62	49.09	47.61	46.5	45.33	44.35	43.47	26.32
273	62.03	61.62	49.09	47.61	46.5	45.33	44.35	43.47	26.32
274	62.03	61.55	49.11	47.54	46.41	45.24	44.38	43.42	26.32
275	62.01	61.53	49.09	47.61	46.48	45.3	44.44	43.45	26.32
276	62.01	61.53	49.09	47.61	46.48	45.3	44.44	43.45	26.32
277	61.95	61.46	49.07	47.58	46.48	45.35	44.42	43.51	26.33
278	61.9	61.44	49.09	47.56	46.5	45.26	44.4	43.47	26.32
279	61.68	61.42	49.15	47.58	46.5	45.3	44.4	43.47	26.33
280	61.68	61.42	49.15	47.58	46.5	45.3	44.4	43.47	26.33
281	61.68	61.38	49.13	47.63	46.46	45.33	44.44	43.56	26.33
282	61.62	61.31	49.04	47.58	46.52	45.35	44.46	43.51	26.33
283	61.55	61.29	49.09	47.65	46.59	45.35	44.49	43.53	26.33
284	61.55	61.29	49.09	47.65	46.59	45.35	44.49	43.53	26.33
285	61.51	61.27	49.13	47.65	46.52	45.37	44.57	43.58	26.32
286	61.49	61.22	49.02	47.61	46.54	45.33	44.46	43.49	26.33
287	61.49	61.22	49.02	47.61	46.54	45.33	44.46	43.49	26.33
288	61.49	61.2	49.13	47.63	46.57	45.39	44.49	43.49	26.32
289	61.44	61.14	49.07	47.61	46.54	45.37	44.4	43.6	26.33
290	61.35	61.09	49.13	47.67	46.54	45.39	44.53	43.49	26.33
291	61.35	61.09	49.13	47.67	46.54	45.39	44.53	43.49	26.33
292	61.31	61.07	49.13	47.63	46.59	45.42	44.53	43.56	26.33
293	61.29	61.07	49.13	47.63	46.63	45.39	44.51	43.62	26.33
294	61.2	60.98	49.18	47.65	46.59	45.44	44.51	43.6	26.33
295	61.2	60.98	49.18	47.65	46.59	45.44	44.51	43.6	26.33
296	61.22	60.96	49.15	47.65	46.61	45.37	44.51	43.6	26.33
297	61.2	60.92	49.18	47.63	46.63	45.48	44.6	43.6	26.33
298	61.2	60.92	49.18	47.63	46.63	45.48	44.6	43.6	26.33
299	61.11	60.87	49.15	47.67	46.61	45.44	44.6	43.67	26.33
300	61.07	60.83	49.15	47.69	46.63	45.46	44.53	43.58	26.32
301	61.03	60.81	49.15	47.69	46.63	45.53	44.57	43.65	26.32
302	61.03	60.81	49.15	47.69	46.63	45.53	44.57	43.65	26.32
303	61	60.78	49.13	47.69	46.57	45.44	44.53	43.69	26.32
304	60.94	60.74	49.15	47.67	46.65	45.5	44.57	43.65	26.33
305	60.92	60.72	49.11	47.63	46.68	45.44	44.55	43.69	26.33
306	60.92	60.72	49.11	47.63	46.68	45.44	44.55	43.69	26.33
307	60.89	60.67	49.15	47.65	46.65	45.5	44.55	43.69	26.33
308	60.87	60.65	49.18	47.72	46.76	45.57	44.66	43.71	26.34

309	60.87	60.65	49.18	47.72	46.76	45.57	44.66	43.71	26.34
310	60.74	60.57	49.18	47.67	46.65	45.53	44.62	43.71	26.34
311	60.65	60.57	49.13	47.69	46.68	45.53	44.64	43.78	26.34
312	60.57	60.52	49.11	47.69	46.65	45.5	44.62	43.67	26.34
313	60.57	60.52	49.11	47.69	46.65	45.5	44.62	43.67	26.34
314	60.48	60.5	49.11	47.69	46.7	45.48	44.62	43.71	26.33
315	60.39	60.43	49.13	47.67	46.63	45.53	44.66	43.73	26.33
316	60.35	60.37	49.11	47.67	46.7	45.59	44.57	43.69	26.33
317	60.35	60.37	49.11	47.67	46.7	45.59	44.57	43.69	26.33
318	60.32	60.35	49.15	47.69	46.65	45.55	44.62	43.62	26.33
319	60.26	60.3	49.15	47.74	46.65	45.5	44.64	43.67	26.33
320	60.26	60.3	49.15	47.74	46.65	45.5	44.64	43.67	26.33
321	60.19	60.3	49.18	47.67	46.68	45.53	44.71	43.71	26.33
322	60.17	60.26	49.13	47.69	46.65	45.46	44.6	43.67	26.33
323	60.13	60.24	49.15	47.69	46.7	45.59	44.69	43.73	26.34
324	60.13	60.24	49.15	47.69	46.7	45.59	44.69	43.73	26.34
325	60.06	60.19	49.09	47.72	46.7	45.59	44.66	43.71	26.33
326	60.02	60.15	49.07	47.61	46.61	45.53	44.64	43.73	26.33
327	60.02	60.15	49.07	47.61	46.61	45.53	44.64	43.73	26.33
328	59.97	60.1	49.09	47.72	46.7	45.44	44.69	43.69	26.33
329	59.91	60.06	49.13	47.74	46.65	45.57	44.69	43.76	26.33
330	59.86	60.06	49.07	47.74	46.65	45.55	44.69	43.76	26.33
331	59.86	60.06	49.07	47.74	46.65	45.55	44.69	43.76	26.33
332	59.82	60	49.09	47.69	46.65	45.53	44.64	43.71	26.34
333	59.78	59.97	49.15	47.69	46.7	45.59	44.73	43.78	26.34
334	59.8	59.95	49.18	47.72	46.74	45.57	44.66	43.73	26.34
335	59.8	59.95	49.18	47.72	46.74	45.57	44.66	43.73	26.34
336	59.75	59.93	49.09	47.67	46.7	45.59	44.66	43.71	26.34
337	59.71	59.89	49.11	47.69	46.7	45.59	44.66	43.73	26.35
338	59.62	59.84	49.11	47.69	46.7	45.57	44.71	43.8	26.35
339	59.62	59.84	49.11	47.69	46.7	45.57	44.71	43.8	26.35
340	59.6	59.8	49.07	47.65	46.7	45.55	44.66	43.71	26.35
341	59.53	59.78	49.13	47.67	46.65	45.53	44.71	43.82	26.35
342	59.53	59.78	49.13	47.67	46.65	45.53	44.71	43.82	26.35
343	59.47	59.67	49.04	47.67	46.68	45.57	44.69	43.73	26.35
344	59.47	59.67	49.09	47.69	46.65	45.61	44.69	43.78	26.36
345	59.42	59.64	49.07	47.69	46.7	45.55	44.66	43.73	26.36
346	59.42	59.64	49.07	47.69	46.7	45.55	44.66	43.73	26.36
347	59.34	59.62	49.11	47.72	46.68	45.57	44.64	43.76	26.36
348	59.25	59.56	49.04	47.63	46.63	45.59	44.71	43.76	26.36
349	59.21	59.51	49.11	47.69	46.68	45.55	44.66	43.73	26.37
350	59.21	59.51	49.11	47.69	46.68	45.55	44.66	43.73	26.37
351	59.16	59.47	49.02	47.61	46.63	45.59	44.71	43.82	26.37
352	59.16	59.45	49.02	47.61	46.63	45.5	44.62	43.71	26.37
353	59.16	59.45	49.02	47.61	46.63	45.5	44.62	43.71	26.37
354	59.1	59.47	49.09	47.63	46.68	45.55	44.62	43.71	26.37
355	59.07	59.45	49.04	47.61	46.65	45.64	44.69	43.78	26.37
356	58.99	59.34	49.04	47.61	46.65	45.55	44.62	43.73	26.37
357	58.99	59.34	49.04	47.61	46.65	45.55	44.62	43.73	26.37
358	58.96	59.34	49.07	47.63	46.7	45.55	44.64	43.71	26.37
359	58.94	59.29	49	47.61	46.68	45.55	44.69	43.73	26.37
360	58.94	59.29	49	47.61	46.68	45.55	44.69	43.73	26.37

361	58.88	59.25	48.98	47.54	46.65	45.48	44.64	43.67	26.37
362	58.85	59.25	49.02	47.58	46.7	45.5	44.73	43.76	26.38
363	58.77	59.16	48.89	47.58	46.57	45.55	44.64	43.69	26.38
364	58.77	59.16	48.89	47.58	46.57	45.55	44.64	43.69	26.38
365	58.68	59.12	48.91	47.56	46.59	45.44	44.69	43.73	26.38
366	58.64	59.1	48.96	47.56	46.54	45.57	44.64	43.71	26.38
367	58.64	59.07	48.93	47.54	46.61	45.48	44.62	43.73	26.38
368	58.64	59.07	48.93	47.54	46.61	45.48	44.62	43.73	26.38
369	58.57	59.05	48.96	47.58	46.54	45.46	44.69	43.69	26.38
370	58.53	58.99	48.96	47.58	46.57	45.61	44.64	43.69	26.38
371	58.53	58.99	48.96	47.58	46.57	45.61	44.64	43.69	26.38
372	58.46	58.92	48.93	47.52	46.59	45.55	44.57	43.67	26.37
373	58.44	58.9	48.87	47.52	46.54	45.5	44.69	43.76	26.38
374	58.39	58.85	48.84	47.56	46.57	45.53	44.57	43.71	26.38
375	58.39	58.85	48.84	47.56	46.57	45.53	44.57	43.71	26.38
376	58.33	58.81	48.84	47.54	46.5	45.55	44.62	43.73	26.38
377	58.33	58.79	48.84	47.47	46.54	45.48	44.6	43.71	26.38
378	58.33	58.79	48.84	47.47	46.54	45.48	44.6	43.71	26.38
379	58.31	58.79	48.91	47.52	46.57	45.5	44.6	43.69	26.38
380	58.26	58.72	48.89	47.47	46.52	45.53	44.64	43.73	26.39
381	58.24	58.72	48.87	47.5	46.54	45.48	44.6	43.62	26.39
382	58.24	58.72	48.87	47.5	46.54	45.48	44.6	43.62	26.39
383	58.24	58.66	48.82	47.52	46.57	45.5	44.6	43.62	26.4
384	58.22	58.61	48.78	47.38	46.52	45.48	44.55	43.67	26.4
385	58.22	58.61	48.78	47.38	46.52	45.48	44.55	43.67	26.4
386	58.22	58.61	48.8	47.43	46.5	45.48	44.57	43.62	26.4
387	58.2	58.61	48.84	47.5	46.54	45.53	44.69	43.73	26.41
388	58.11	58.53	48.8	47.41	46.57	45.55	44.66	43.71	26.41
389	58.11	58.53	48.8	47.41	46.57	45.55	44.66	43.71	26.41
390	58.04	58.5	48.82	47.43	46.52	45.5	44.6	43.69	26.41
391	57.96	58.48	48.8	47.45	46.57	45.46	44.62	43.71	26.41
392	57.89	58.39	48.73	47.43	46.54	45.5	44.62	43.71	26.41
393	57.89	58.39	48.73	47.43	46.54	45.5	44.62	43.71	26.41
394	57.87	58.42	48.78	47.38	46.54	45.48	44.57	43.65	26.41
395	57.8	58.37	48.78	47.41	46.5	45.48	44.6	43.62	26.41
396	57.8	58.37	48.78	47.41	46.5	45.48	44.6	43.62	26.41
397	57.71	58.28	48.76	47.41	46.48	45.48	44.57	43.62	26.4
398	57.67	58.22	48.67	47.41	46.43	45.42	44.49	43.6	26.4
399	57.63	58.2	48.73	47.3	46.41	45.46	44.53	43.6	26.4
400	57.63	58.2	48.73	47.3	46.41	45.46	44.53	43.6	26.4
401	57.65	58.2	48.69	47.34	46.39	45.39	44.53	43.53	26.4
402	57.56	58.11	48.65	47.27	46.37	45.35	44.46	43.62	26.4
403	57.56	58.11	48.65	47.27	46.37	45.35	44.46	43.62	26.4
404	57.5	58.13	48.67	47.36	46.41	45.35	44.55	43.56	26.4
405	57.5	58.11	48.69	47.25	46.46	45.42	44.57	43.69	26.41
406	57.45	58.09	48.67	47.32	46.37	45.42	44.53	43.6	26.41
407	57.45	58.09	48.67	47.32	46.37	45.42	44.53	43.6	26.41
408	57.36	58	48.62	47.32	46.37	45.3	44.46	43.6	26.42
409	57.32	58	48.65	47.3	46.39	45.35	44.53	43.6	26.42
410	57.32	58	48.65	47.3	46.39	45.35	44.53	43.6	26.42
411	57.28	58	48.56	47.25	46.37	45.42	44.55	43.62	26.43
412	57.28	57.91	48.56	47.3	46.34	45.37	44.49	43.6	26.43

413	57.25	57.93	48.58	47.34	46.41	45.37	44.49	43.62	26.43
414	57.25	57.93	48.58	47.34	46.41	45.37	44.49	43.62	26.43
415	57.17	57.87	48.58	47.3	46.39	45.42	44.49	43.6	26.44
416	57.19	57.85	48.58	47.27	46.37	45.37	44.44	43.6	26.43
417	57.12	57.76	48.53	47.27	46.37	45.35	44.51	43.62	26.44
418	57.12	57.76	48.53	47.27	46.37	45.35	44.51	43.62	26.44
419	57.01	57.76	48.58	47.27	46.32	45.44	44.51	43.56	26.44
420	56.99	57.76	48.58	47.27	46.41	45.33	44.46	43.56	26.44
421	56.99	57.76	48.58	47.27	46.41	45.33	44.46	43.56	26.44
422	56.9	57.67	48.47	47.19	46.32	45.35	44.4	43.53	26.44
423	56.88	57.65	48.49	47.21	46.34	45.33	44.46	43.6	26.44
424	56.82	57.6	48.4	47.19	46.37	45.33	44.44	43.58	26.44
425	56.82	57.6	48.4	47.19	46.37	45.33	44.44	43.58	26.44
426	56.82	57.58	48.49	47.21	46.28	45.26	44.46	43.49	26.44
427	56.77	57.52	48.42	47.19	46.23	45.24	44.38	43.49	26.44
428	56.71	57.47	48.47	47.14	46.23	45.24	44.38	43.51	26.44
429	56.71	57.47	48.47	47.14	46.23	45.24	44.38	43.51	26.44
430	56.66	57.45	48.38	47.19	46.26	45.24	44.44	43.49	26.44
431	56.66	57.41	48.4	47.12	46.21	45.22	44.38	43.47	26.44
432	56.66	57.41	48.4	47.12	46.21	45.22	44.38	43.47	26.44
433	56.57	57.39	48.38	47.12	46.3	45.3	44.4	43.53	26.45
434	56.57	57.39	48.38	47.12	46.21	45.28	44.42	43.56	26.45
435	56.55	57.34	48.38	47.1	46.23	45.24	44.33	43.47	26.45
436	56.55	57.34	48.38	47.1	46.23	45.24	44.33	43.47	26.45
437	56.49	57.28	48.38	47.07	46.15	45.19	44.35	43.4	26.45
438	56.44	57.25	48.38	47.05	46.23	45.22	44.4	43.45	26.46
439	56.44	57.25	48.38	47.05	46.23	45.22	44.4	43.45	26.46
440	56.35	57.19	48.34	47.05	46.15	45.19	44.35	43.49	26.46
441	56.38	57.17	48.34	47.1	46.19	45.24	44.38	43.47	26.46
442	56.35	57.17	48.31	47.01	46.12	45.19	44.24	43.36	26.46
443	56.35	57.17	48.31	47.01	46.12	45.19	44.24	43.36	26.46
444	56.33	57.12	48.34	47.01	46.1	45.19	44.35	43.42	26.46
445	56.29	57.08	48.25	46.99	46.17	45.13	44.31	43.47	26.46
446	56.29	57.08	48.25	46.99	46.17	45.13	44.31	43.47	26.46
447	56.22	57.01	48.29	47.01	46.08	45.22	44.33	43.4	26.46
448	56.25	56.99	48.29	46.96	46.1	45.15	44.26	43.4	26.46
449	56.18	56.99	48.2	46.94	46.1	45.11	44.29	43.4	26.46
450	56.18	56.99	48.2	46.94	46.1	45.11	44.29	43.4	26.46
451	56.2	56.95	48.18	46.94	46.12	45.13	44.29	43.4	26.46
452	56.14	56.9	48.25	46.99	46.12	45.19	44.33	43.4	26.47
453	56.05	56.84	48.18	46.96	46.03	45.08	44.24	43.34	26.47
454	56.05	56.84	48.18	46.96	46.03	45.08	44.24	43.34	26.47
455	56	56.84	48.23	46.9	46.01	45.08	44.26	43.38	26.46
456	56	56.79	48.18	46.92	45.99	45.13	44.26	43.36	26.46
457	56	56.79	48.18	46.92	45.99	45.13	44.26	43.36	26.46
458	55.96	56.79	48.11	46.83	45.99	45.11	44.24	43.38	26.46
459	55.89	56.68	48.07	46.85	45.99	45.06	44.22	43.29	26.46
460	55.87	56.68	48.11	46.85	46.01	45.08	44.18	43.29	26.46
461	55.87	56.68	48.11	46.85	46.01	45.08	44.18	43.29	26.46
462	55.83	56.6	48.05	46.81	45.9	45.02	44.2	43.29	26.46
463	55.78	56.62	48.09	46.85	45.99	45.02	44.18	43.25	26.46
464	55.78	56.62	48.09	46.85	45.99	45.02	44.18	43.25	26.46

465	55.72	56.6	48.05	46.79	45.97	45.08	44.22	43.36	26.46
466	55.63	56.55	48.05	46.7	45.9	45	44.11	43.25	26.47
467	55.63	56.53	48.09	46.79	45.99	45	44.13	43.27	26.47
468	55.63	56.53	48.09	46.79	45.99	45	44.13	43.27	26.47
469	55.61	56.49	48.03	46.83	45.9	45	44.13	43.27	26.48
470	55.59	56.44	47.96	46.79	45.92	44.95	44.15	43.27	26.48
471	55.59	56.44	47.96	46.79	45.92	44.95	44.15	43.27	26.48
472	55.59	56.46	48.05	46.74	45.9	45	44.15	43.29	26.49
473	55.5	56.35	48	46.76	45.88	45	44.2	43.25	26.49
474	55.46	56.33	47.98	46.7	45.86	44.95	44.09	43.23	26.49
475	55.46	56.33	47.98	46.7	45.86	44.95	44.09	43.23	26.49
476	55.41	56.31	47.96	46.72	45.88	45	44.15	43.2	26.49
477	55.35	56.29	47.96	46.65	45.88	45	44.09	43.2	26.5
478	55.32	56.2	47.92	46.7	45.86	44.95	44.09	43.25	26.49
479	55.32	56.2	47.92	46.7	45.86	44.95	44.09	43.25	26.49
480	55.32	56.2	47.89	46.72	45.84	44.93	44.04	43.16	26.5
481	55.32	56.22	47.96	46.7	45.88	44.97	44.11	43.25	26.5
482	55.32	56.22	47.96	46.7	45.88	44.97	44.11	43.25	26.5
483	55.28	56.16	47.87	46.65	45.86	44.97	44.07	43.25	26.5
484	55.17	56.11	47.85	46.68	45.81	44.93	44.09	43.23	26.51
485	55.17	56.11	47.85	46.65	45.84	44.88	44.09	43.18	26.5
486	55.17	56.11	47.85	46.65	45.84	44.88	44.09	43.18	26.5
487	55.08	56.03	47.78	46.65	45.79	44.91	44.04	43.2	26.51
488	55.08	56.03	47.83	46.57	45.77	44.86	44.02	43.18	26.5
489	55.04	56	47.8	46.54	45.79	44.88	44	43.14	26.51
490	55.04	56	47.8	46.54	45.79	44.88	44	43.14	26.51
491	55.02	55.96	47.76	46.54	45.77	44.88	44.04	43.14	26.5
492	54.93	55.87	47.76	46.52	45.73	44.82	43.93	43.09	26.5
493	54.93	55.87	47.76	46.52	45.73	44.82	43.93	43.09	26.5
494	54.93	55.89	47.74	46.59	45.7	44.77	43.98	43.11	26.5
495	54.89	55.87	47.74	46.57	45.75	44.86	44	43.11	26.5
496	54.82	55.74	47.69	46.48	45.61	44.82	44	43.11	26.5
497	54.82	55.74	47.69	46.48	45.61	44.82	44	43.11	26.5
498	54.86	55.83	47.65	46.5	45.66	44.75	43.93	43.07	26.51
499	54.8	55.76	47.65	46.43	45.61	44.82	43.96	43.05	26.51