PROCEEDINGS OF THE 2ND INTERNATIONAL CONFERENCE ON BIODENTAL ENGINEERING, BIODENTAL 2012, PORTO, PORTUGAL, 7–8 DECEMBER 2012

Biodental Engineering II

Editors

R.M. Natal Jorge, J.C. Reis Campos, João Manuel R.S. Tavares,
Mário A.P. Vaz & Sónia M. Santos
Universidade do Porto, Porto, Portugal

CRC Press
Taylor & Francis Group
Boca Raton London New York Leiden

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business
A BALKEMA BOOK

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

Typeset by MPS Limited, Chennai, India
Printed and bound in Great Britain by CPI Group (UK) Ltd, Croydon, CR0 4YY.

Published by: CRC Press/Balkema
P.O. Box 11320, 2301 EH, Leiden, The Netherlands
e-mail: Pub.NL@taylorandfrancis.com
www.crcpress.com – www.taylorandfrancis.com

ISBN: 978-1-138-00131-2 (Hardback)
ISBN: 978-1-315-79826-4 (eBook PDF)

Biodental Engineering II – Natal Jorge et al (Eds)
© 2014 Taylor & Francis Group, London, ISBN 978-1-138-00131-2

Preface

This book contains full papers presented at BIODENTAL 2012 – 2nd International Conference on Biodental Engineering, which was held in Porto, Portugal, during the period 7–8 December 2012. The event had 2 invited lectures, and 46 contributed presentations originated from 8 countries: Brazil, Croatia, France, Germany, Iran, Poland, Portugal and Spain

The dentistry is a branch of medicine with its own peculiarities and very diverse areas of action which means that it can be considered as interdisciplinary field. The use of new techniques and technologies is currently the subject of great interest, and this conference was intended to be a privileged space for discussion among all stakeholders.

The purpose of these BIODENTAL Conferences on Biodental Engineering, initiated in 2009, is to solidify knowledge in the field of bioengineering applied to dentistry promoting a comprehensive forum for discussion on the recent advances in the related fields in order to identify potential collaboration between researchers of different sciences. Henceforth, BIODENTAL 2012 brought together researchers representing fields related to Biomechanical disorders, Orthodontics, Implantology, Aesthetics, Dental, Medical device, Medical imaging.

The conference co-chairs would like to take this opportunity to express gratitude to all sponsors, to all members of the Scientific Committee, to all Invited Lecturers, to all Session-Chairs and to all Authors for submitting and sharing their knowledge.

R.M. Natal Jorge
J.C. Reis Campos
João Manuel R. S. Tavares
Mário A.P. Vaz
Sónia M. Santos
(Conference co-chairs)

Biodental Engineering II – Natal Jorge et al (Eds)
© 2014 Taylor & Francis Group, London, ISBN 978-1-138-00131-2

Scientific Committee

All works submitted to BIODENTAL 2012 were evaluated by an International Scientific Committee composed by 44 expert researchers from recognized institutions:

- Afonso Pinhão Ferreira, University of Porto, Portugal
- André Correia, University of Porto, Portugal
- Begoña Calvo Calzada, University of Zaragoza, Spain
- Cláudia Barros Machado, CESPU, Portugal
- Cornelia Kober, Hamburg University of Applied Sciences, Germany
- Daniela Iacoviello, Sapienza University of Rome, Italy
- Edson Capello, UNESP, Brazil
- Eduardo Borges Pires, Technical University of Lisbon, Portugal
- Elza Maria Morais Fonseca, Polytechnical Institute of Bragança, Portugal
- Estefânia Peña Baquedano, University of Zaragoza, Spain
- Estevam Las Casas, Federal University of Minas Gerais, Brazil
- Fernanda Gentil, IDMEC – FEUP, Portugal
- Gerhard A. Holzapfel, Graz University of Technology, Austria
- Helena Figueiral Ioannis Misirlis, University of Patras, Greece
- Iracema Braga, Federal University of Minas Gerais, Brazil
- João Carlos Pinho, University of Porto, Portugal
- João Manuel Tavares, University of Porto, Portugal
- João Paulo Flores Fernandes, University of Minho, Portugal
- Joaquim Gabriel, Universidade do Porto, Portugal
- John Middleton, Cardiff University, UK
- Jorge Marinho, IPO, Portugal
- José Antonio de Oliveira Simões, University of Aveiro, Portugal
- José Mário Rocha, University of Porto, Portugal
- Kazem Alemzadeh, University of Bristol, UK
- Leopoldo Forner Navarro, University of València, Spain
- Lídia Carvalho, University of Aveiro, Portugal
- Luis Geraldo Vaz, UNESP, Brazil
- Luís Pires Lopes, Universidade de Lisboa, Portugal
- Marcos Pinotti Barbosa, Federal University of Minas Gerais, Brazil
- Maria Cristina Manzanares Céspedes, University of Barcelona, Spain
- Mário Vasconcelos, University of Porto, Portugal
- Mário Vaz, University of Porto, Portugal
- Miguel Pinto, University of Porto, Portugal
- Oliver Röhrle,University of Stuttgart, Germany
- Pablo Jesús Rodríguez Cervantes, Universitat Jaume I, Spain
- Paula Vaz, University of Porto, Portugal
- Paulo Alexandre Gonçalves Piloto, Polytechnical Institute of Bragança, Portugal
- Paulo Melo, University of Porto, Portugal
- Paulo Rui Fernandes, Technical University of Lisbon, Portugal
- Pedro Mesquita, University of Porto, Portugal
- Pedro Miguel Gomes Nicolau, University of Coimbra, Portugal
- Reis Campos, University of Porto, Portugal
- Renato Natal Jorge, University of Porto, Portugal
- Sampaio Fernandes, University of Porto, Portugal

Biodental Engineering II – Natal Jorge et al (Eds)
© 2014 Taylor & Francis Group, London, ISBN 978-1-138-00131-2

Numerical model of thermal necrosis due a dental drilling process

E.M.M. Fonseca, K. Magalhães & M.G. Fernandes
Polytechnic Institute of Bragança, Bragança, Portugal

M.P. Barbosa & G. Sousa
University of Minas Gerais, Belo Horizonte, Brasil

ABSTRACT: The main goal of this paper is to present a numerical model for studying the thermal necrosis due a dental drilling process. The finite element method was used with Ansys program for the transient thermal analysis. Also an experimental process is explained to determine the thermal occurrence in a pork mandible. The increase of temperature produced during the drilling is compared using the two different methodologies. According the obtained results, the numerical model could be a technique to induce appropriated results without using in-vivo models.

1 INTRODUCTION

When cutting tools, as drills, are used to cut a material, heat is produced and temperature increases of both the tool and material. The drilling parameters (drill speed, drill depth, drill diameter, applied load and feed rate) are important to determine the effect on thermal necrosis. When the irrigation is possible, the effect is decreasing the temperature rise in bone (Davidson, 1999). Bone is a poor conductor of heat, and heat generation is a common problem during any type of drilling (Hillery, 1999). The value on the threshold of temperature above which cell necrosis occurs have been presented by different researchers. The literature shows that if the temperature rises above 55°C for a period of longer than 30s, serious bone damage will be done (Hillery, 1999).

2 MATERIALS AND METHODS

In order to model the thermal necrosis due a dental drilling process, a finite element method was used with Ansys program and a comparison with an experimental methodology using a pork mandible. The numerical analysis was conducted with transient heat conduction by modelling the heat flux from the drill process, as represented in figure 1.

The finite element mesh constituted by cortical and trabecular dental bone has a hole with diameter equal to the cylindrical part of the drill, figure 2. A solid finite element (Solid90) with 20 nodes was used in Ansys program. A typical mesh with an element length equal to 0.5 mm was chosen. An initial-boundary condition with a temperature $T0 = 37°C$ was considered in all dental bone model.

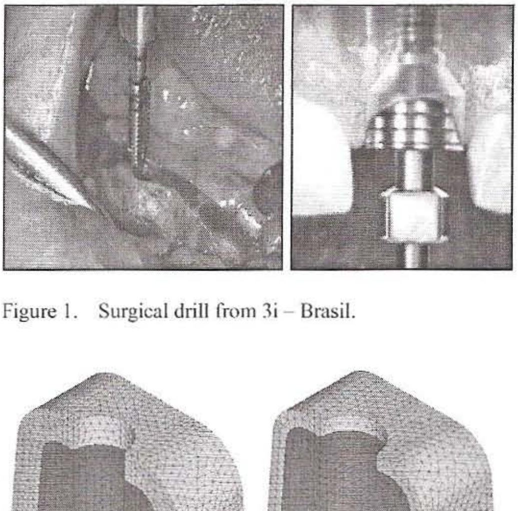

Figure 1. Surgical drill from 3i – Brasil.

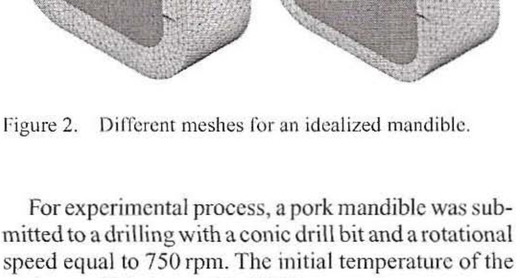

Figure 2. Different meshes for an idealized mandible.

For experimental process, a pork mandible was submitted to a drilling with a conic drill bit and a rotational speed equal to 750 rpm. The initial temperature of the pork mandible is equal to 20°C.

Figure 3 shows the experimental setup used during the drilling. The experimental results are obtained with a Flir infrared thermography camera.

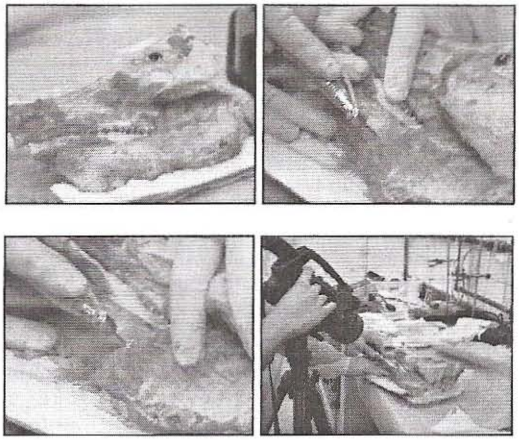

Figure 3. Experimental setup.

3 NUMERICAL MODEL

3.1 *Drilling parameters*

The modelling of heat propagation from drill process was described by a heat flux density q received in the bone surface.

The heat flux density is according the following equation (Basiaga, 2011):

$$q=P_c/S \quad (\mathrm{W/m^2}) \tag{1}$$

where P_c = total cutting power, and S = surface area. The total cutting power is a combination between the power derived from the feed component (P_f) and the power derived from the cutting torque (P_M).

$$P_c=P_f+P_M \quad (\mathrm{W}) \tag{2}$$

The following expressions give particular results for each relation (Basiaga, 2011):

$$P_f=V_f \times F_{fw} \quad (\mathrm{W}) \tag{3}$$

$$P_M=M_W \times n \times 2\pi/60 \quad (\mathrm{W}) \tag{4}$$

where V_f = feed ratio speed (m/s), F_{fw} = axial cutting force (N), M_w = cutting torque (Nm), and n = rotational speed (rpm).

According the references (Hillery, 1999; Hillery, 1996), using the same drill bit diameter and geometry there is an exponential falling-off of the cutting torque from 14.5×10^{-3} Nm at 400 rpm to an asymptote of 10×10^{-3} Nm at 2000 rpm. And also an exponential falling-off of the thrust force from 48 N at 400 rpm to an asymptote of 23 N at 2000 rpm.

In the surgical process used in ***3i - Brasil*** different steps for dental drilling are considered, always with a speed rotation equal to 750 rpm during 10 s:

- 1st step: initial perforation with a spherical round drill to punch the position;
- 2nd step: specific drill with a diameter d = 2 mm;
- 3rd step: conic drill with d = 3.2 mm and length l = 10 mm;
- 4th step: conic drill with d = 4.1 mm and l = 10 mm.

Table 1. The drilling parameters.

Final conic drill bit	
d	4.1 mm
l	10 mm
V_f	50 mm/min
n	750 rpm
M_W	12.5×10^{-3} Nm
F_{fw}	37.5 N
q	7.14 kW/m^2

Table 2. Bone thermal properties.

Properties	Bone	C1	C2	C3	C4
Density, kg/m^3	Cortical		2100		
	Trabecular	2200	1100	2200	1100
Conductivity, W/mK	Cortical		0.4		
	Trabecular		0.5		
Specific heat, J/kgK	Cortical		1260		
	Trabecular		1490		
Cortical thickness, mm		2	2	1	1

This standard drill for the last step is always the most used. According this situation the parameters used in the numerical simulation corresponds to this surgical drill with straight shank, 4.1 × 10 and a rotational speed equal to 750 rpm.

The feed rate speed varies according the surgeon, and it was chosen a value equal to 50 mm/min.

Table 1 shows the parameters used in the numerical simulation.

3.2 *Geometries and material properties*

The geometry considered in all numerical simulations represents a part of a dental bone with a hollow cavity equal to the drill bit diameter and a depth equal to 10 mm.

Four different idealized mandibular cross sections were used. Cortical bone of 2 mm thickness with medium density (C1) or low density trabecular bone (C2), and cortical bone of 1 mm thickness with medium density (C3) or low density trabecular bone (C4).

Based in the literature (Davidson, 1999; Hillery, 1996; Mazzullo, 1991; Lin, 2007) the thermal properties for cortical and trabecular bone are presented in table 2.

A solid mandibular cross-section with different nodal positions, neighbourhood to the drill hole (t = 0 mm) and at a distance t = 0.5 mm, is presented in figure 4.

Six different positions are considered to measure the thermal necrosis, two nodal locations in cortical

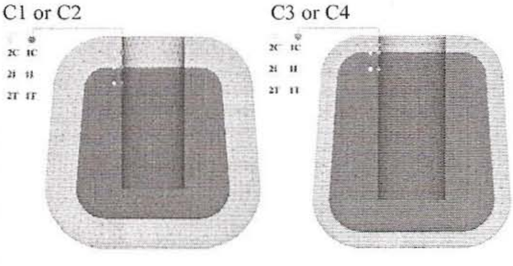

Figure 4. Nodal positions for each model.

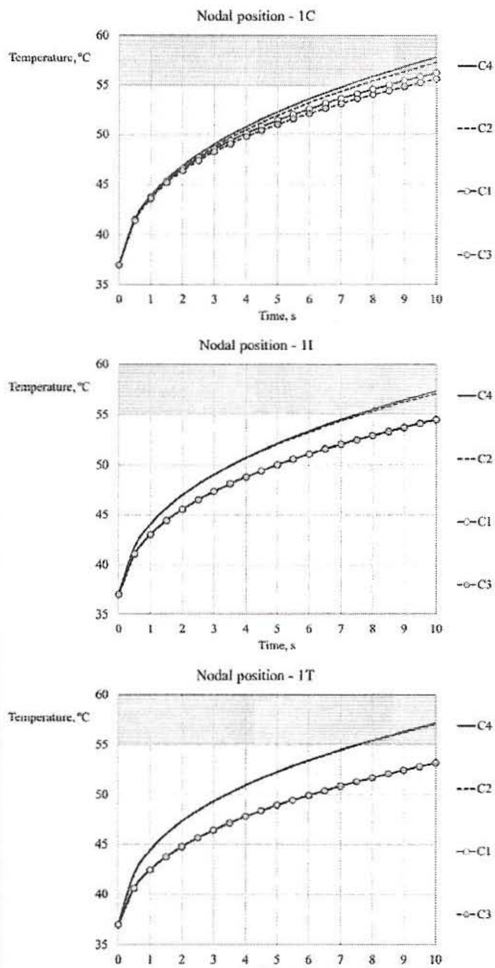

Figure 5. Time-temperature history for 1C, 1I, 1T.

(1C, 2C), trabecular (1T, 2T) and intermediate zone (1I, 2I).

3.3 *Numerical results*

Figure 5 and 6 show different graphics with all time-temperature history for all nodal positions. The grey zone represents the bone damage on the threshold of 55°C. Figure 5 represents the numerical results

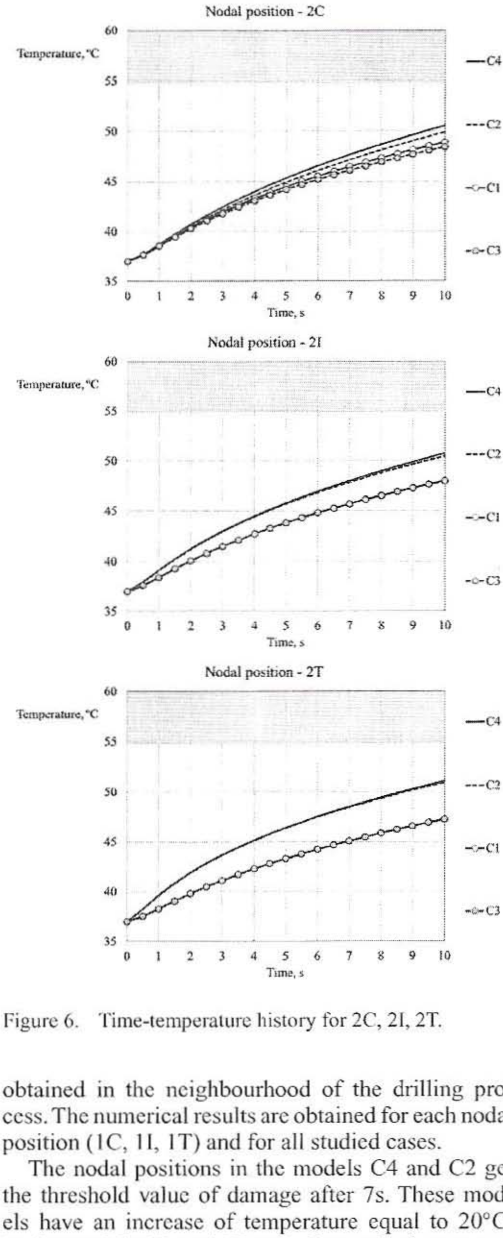

Figure 6. Time-temperature history for 2C, 2I, 2T.

obtained in the neighbourhood of the drilling process. The numerical results are obtained for each nodal position (1C, 1I, 1T) and for all studied cases.

The nodal positions in the models C4 and C2 get the threshold value of damage after 7s. These models have an increase of temperature equal to 20°C. In the models C1 and C3 only the cortical zone gets the threshold value of bone damage after 9s. And they have an increase of temperature equal to 15°C–17°C.

Figure 6 represents the second position of the nodal temperatures in all studied cases.

Studied cases C1 and C3 have a different behaviour in trabecular and intermediate zone with lesser temperatures.

The effect of the cortical thickness doesn't affect with relevance the obtained numerical values. But the density in trabecular bone interferes in all studied cases.

The medium density of the trabecular bone (C1 and C3) offers more thermal resistance than the lower bone density (C2 and C4).

Table 3. Thermal necrosis occurrence, time s.

	Nodal position					
	In the hole t = 0 mm			Distance t = 0.5 mm		
Studied case	1C	1I	1T	2C	2I	2T
C1 or C3	9.0	10.0	–	–	–	–
C2 or C4	7.0	7.5	7.5	–	–	–

Table 4. Bone damage (%) at 1s of exposure 55°C heat.

	Nodal position					
	In the hole t = 0 mm			Distance t = 0.5 mm		
Studied case	1C	1I	1T	2C	2I	2T
C1 or C3	11.1	10.0	–	–	–	–
C2 or C4	14.3	13.3	13.3	–	–	–

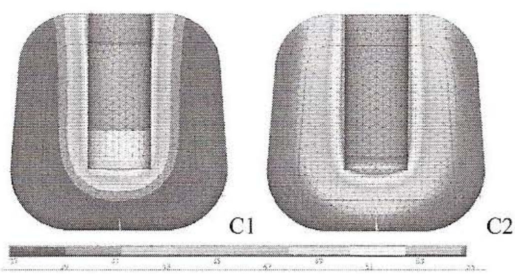

Figure 7. Bone damage (t = 0.25 mm) for cases C1 and C2.

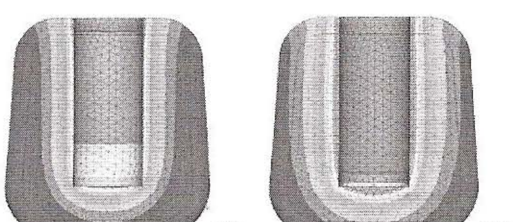

Figure 8. Bone damage (t = 0.25 mm) for cases C3 and C4.

At 0.5 mm in front of the drill there is no bone damage. The increase of temperature is equal of 13°C for models C4 and C2 and 11°C for C1 and C3.

Based in figures 5 and 6, table 3 represents the time instant that thermal necrosis occurs for each study case.

Due the drilling process, the surrounding bone is heated, and the temperature around the drilled bone hole exceeds the critical imposed limit and it is equal to 55°C. The result is the irreversible death of cells, representing the thermal necrosis. Bone cell necrosis or damage, happens when receives heat during a

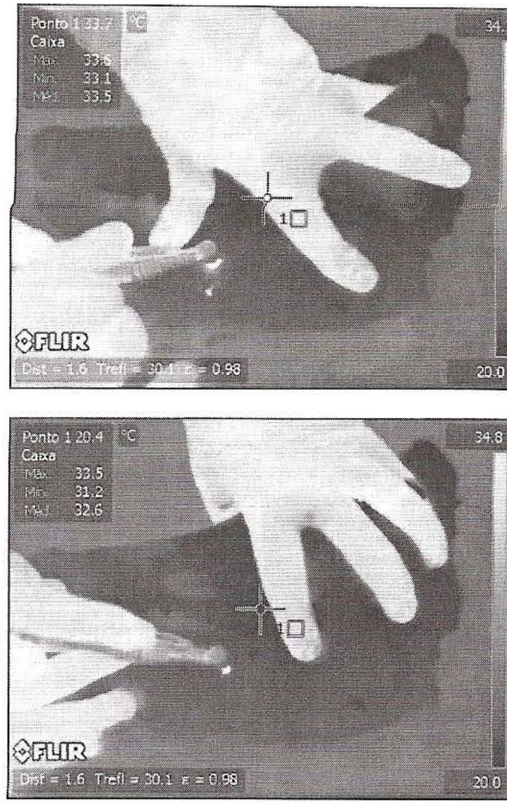

Figure 9. Infrared thermal images without irrigation.

period of time. The temperature threshold levels, for heat induced injury, are time-dependent.

In this work, the damage could be calculated as a percentage of bone damage when receives heat, as proposed by (Fukushima, 2007). Bone cell necrosis, or damage at 100%, occurs when it receives 55°C of heat. Consequently, it is possible to conclude about the amount of bone damage, caused during one-second of exposure to 55°C heat, according an equation as the following:

$$Damage\ (55°C) = (1/time) \times 100\% \qquad (5)$$

In our study, table 4 represents the amount of bone damage, at one second of exposure 55°C heat.

The worst positions are neighbourhood to the drill hole and for cases C2 or C4. For one exposure at 55°C of heat, the amount of bone damage is equal to 14.3%. The nodal positions at 0.5 mm, don't present any bone damage. Figures 7 and 8 represent the extension of bone damage, (ash zone) at the end of a drilling process (10s) for all studied cases.

4 EXPERIMENTAL PROCESS

4.1 *Infrared thermal images*

The results obtained with the experimental process are show in figures 9 and 10.

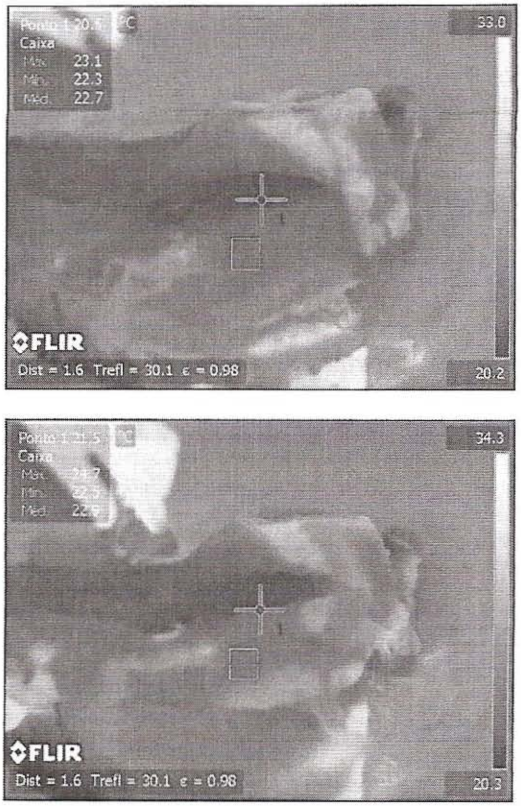

Figure 10. Infrared thermal images with irrigation.

Two different types of tests were produced using irrigation during the drilling process and without irrigation. The recorded temperatures are in the surface of the pork mandible during the drilling process.

Figure 9 represents the infrared thermal images obtained during the drilling process without irrigation.

Figure 10 represents two images obtained during the drilling process with irrigation.

4.2 *Experimental results*

The increase of temperature is equal to almost 14°C, relative to the initial temperature (20°C) when the experimental test is without irrigation. With irrigation, the increase of temperature is almost equal to 5°C, relative to the initial temperature (20°C) of the pork mandible. Comparing the increase of the temperature obtained in the experimental process without irrigation, the range is similar to the obtained results from numerical analysis.

5 CONCLUSIONS

In this work two different methodologies are presented to assess the thermal necrosis due a dental drilling process.

The numerical model presents a methodology to calculate the amount of bone damage. The parameters selection (drill diameter and rotational speed) are important to increase a surgical planning definition and the prevention of the thermal necrosis.

An experimental methodology could be used, as recording the thermal images.

Comparing the increase of temperature between all methodologies, the range is similar when using the numerical model with higher bone density (C1 or C3) and the drilling without irrigation in the experimental process.

In conclusion, the numerical methodology could be a technique to induce appropriate results, without using in-vivo models.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge to the companies that made possible this work, Implantec, Dmc group and 3i-implants innovation incorporation.

REFERENCES

Basiaga, M., Paszenda, Z., Szewczenko, J., Kaczmarek, M. 2011. Numerical and experimental analyses of drills used in osteosynthesis. *Acta of Bioengineering and Biomechanics* 13(4): 29–36.

Davidson, S.R.H. 1999. *Heat transfer in bone during drilling. Applied Science Master Degree*, University of Toronto, Canada.

Fukushima, H., Hashimoto, Y., Yoshiya, S., Kurosaka, M., Matsuda, M., Kawamura, S., Iwatsubo, T. 2002. Conduction Analysis of Cement Interface Temperature in Total Knee Arthroplasty. *Kobe J. Med. Sci.*, 48: 63–72.

Hillery, M.T., Shuaib, I. 1999. Temperature effects in the drilling of human and bovine bone. *Journal of Materials Processing Technology* 92–93: 302–308.

Hillery *et al*, IMC-13:33–42, Ireland, 1996.

Lin, D., Li, Q., Li, W., Ichim, I., Swain, M. 2007. *Evaluation of dental implant induced bone remodelling by using a 2D Finite Element model. 5th Australian Congress on Applied Mechanics*, ACAM, 2007, Brisbane, Australia.

Mazzullo, S., Paolini, M. Verdi, C. 1991. Numerical simulation of thermal bone necrosis during cementation of femoral prostheses. *Journal of Mathematical Biology*, 29: 475–494.