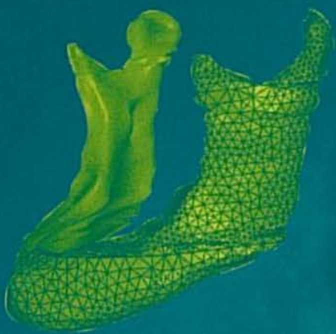

BIODENTAL ENGINEERING

III

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Mário A.P. Vaz
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A BALKEMA BOOK

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Biodental Engineering III

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Table of contents

Biodental Engineering III – Natal Jorge et al. (Eds)
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Preface

Dentistry is a branch of medicine with peculiarities and diverse areas of action, being commonly considered as a very interdisciplinary area. The development, validation and clinical use of more competently techniques and technologies have been of great demand and interest.

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 and end-users from different sciences.

This book contains the full papers presented at the 3rd International Conference on Biodental Engineering (BIODENTAL 2014), which was held in Póvoa do Varzim, Porto, Portugal, in June 22–23. The conference had 2 Invited Lectures, and 72 contributed presentations, which were selected by the conference scientific committee, and originated from 14 countries: Belgium, Brazil, China, Chile, Ecuador, France, Germany, Greece, Italy, Poland, Portugal, Romania, Spain and the United States of America.

During BIODENTAL 2014, several topics and applications were addressed, including biomechanical disorders, orthodontics, implantology, aesthetics, dental medicine, medical devices and medical imaging.

The conference co-chairs would like to take this opportunity to express their gratitude to the conference sponsors, all members of the conference scientific committee, invited lecturers, session-chairs and to all authors for submitting and sharing their knowledge.

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

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Thematic sessions

Under the auspicious of Biodental 2014, two Thematic Sessions were organized:

Bone tissue remodelling numerical analysis

Jorge Belinha, *Instituto de Engenharia Mecânica, Pólo FEUP, Portugal*
António Completo, *Departamento de Engenharia Mecânica, Universidade de Aveiro, Portugal*

Biomaterials in oral rehabilitation

Ricardo de Souza Magini, *Universidade Federal de Santa Catarina, Brazil*
Julio Souza, *Universidade Federal de Santa Catarina, Brazil/Universidade do Minho, Portugal*
Cesar Benfatti, *Universidade Federal de Santa Catarina, Brazil*
Claudia Volpato, *Universidade Federal de Santa Catarina, Brazil*
Márcio Fredel, *Universidade Federal de Santa Catarina, Brazil*
Filipe Silva, *Universidade do Minho, Portugal*
Bruno Henriques, *Universidade do Minho, Portugal*
Mihaela Buciumeanu, *Universidade do Minho, Portugal*

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Scientific committee

All works submitted to BIODENTAL 2014 were evaluated by an International Scientific Committee composed by 55 expert researchers from recognized institutions:

- Afonso Pinhão Ferreira, *University of Porto, Portugal*
- André Correia, *University of Porto, Portugal*
- António Completo, *University of Aveiro, Portugal*
- Carla Roque, *IDMEC, Portugal*
- Christopjh Bourauel, *Bonn University, Germany*
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- Renato Natal Jorge, *University of Porto, Portugal*
- Sampaio Fernandes, *University of Porto, Por*tugal
- Stephen Richmond, *Cardiff University, UK*
- Yongjie Zhang, *Carnegie Mellon University, USA*

Contributed papers

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Fracture resistance of single-tooth implant-supported

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J.F. Piloto
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ABSTRACT: The purpose of this study is to identify and compare the fracture behaviour of the ceramic used in a single-tooth implant-supported. This type of prosthesis is mainly used when a single tooth replacement is needed. Two different materials are tested for the abutment (ceramic and titanium), assuming fully connection to the crown. The implant is made of titanium. The numerical simulations used the concept of continuous damage mechanics to predict crack pattern when loading the tooth in the vertical direction. The ceramic abutment grants an increase of 10% in fracture resistance and is able to accommodate a larger extension of damage material of the crown.

1 INTRODUCTION

Replacing teeth with implant supported restorations is one of the normally used treatments to provide an aesthetic and functionality result. Titanium implants are successful medical devices and their clinical survival rates are good, but the visual colour of the implants and abutments can result in an unnatural appearance. The presence of a gray gingival discoloration may be attributed to a thin gingival tissue thickness in the area around the abutment that is unable of blocking reflective light from the metal abutment surface. To overcome this aesthetic problem, the ceramic abutment has been increasingly used for dental implants, Aydın et al. (2013), Aramouni et al. (2008).

Ceramic material presents good chemical and dimension stability, high strength, tooth like colour, low thermal conductivity and low corrosion potential.

All the implants should have the ability to withstand physiological forces. The material and the geometry of implants should be well tested and analysed to safely design this medical devices. Occlusal forces were reported in the range of 90–370 N and 150 to 235 N in the anterior region, Haraldson et al. (1979) and Paphangkorakit et al. (1997). Loads of this magnitude should be safely supported by this kind of materials, used in implants, abutments and crowns.

This paper deals with the fracture behaviour of a single-tooth implant-supported, considering an implant made of titanium and using two different types of materials in the abutment. The geometry of the implant, abutment and crown is depicted in Figure 1 (solid model in the left and numerical model in the right).

This finite element model uses the incremental procedure to update the state of equilibrium in conjunction with an iterative method, accounting for the nonlinear behaviour of the materials.

The smear approach of cracking or crushing is predicted by the stress level determined by tension or compression, maintaining the continuity of the displacement field, where the material became ineffective.

All specimens were simulated to fracture resistance using compressive load on the cusp surface of the crown. The implant is considered fully restrained in the threaded area.

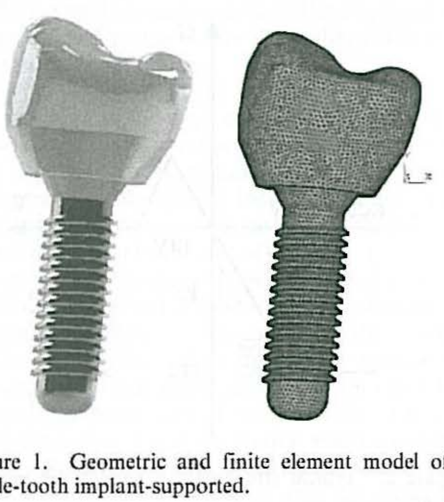


Figure 1. Geometric and finite element model of a single-tooth implant-supported.

The amount of damage is going to be compared between two different models, and typical load displacement curves are also plotted. Stress modification is expected around the damaged volume and results will also be analysed.

2 OBJECTIVES

The objective of this research is to compare the fracture resistance, damage extension and location on ceramic material, depending on the material of the abutment (stiffness of the material).

An incremental loading step is applied in the cusp zone in the direction parallel to implant, until the maximum load bearing is reached. The pattern of cracking and crushing is calculated. Cracking is the ultimate state condition under tension while crushing is represented by compressive stress state.

3 MATERIALS

Two different materials are defined for numerical simulation of this single-tooth implant-supported. The adherence between them is not considered in this research, assuming perfect contact between both. The ceramic material should be considered as brittle material, using adequate constitutive relations and the titanium should be considered as normal ductile material behaviour.

Ceramic material presents higher strength resistance in compression than in tension. Figure 2 represents the mechanical behaviour under uniaxial stress conditions, being the material capable of stress relieving under tension stress. This behaviour is normally used to increase numerical convergence.

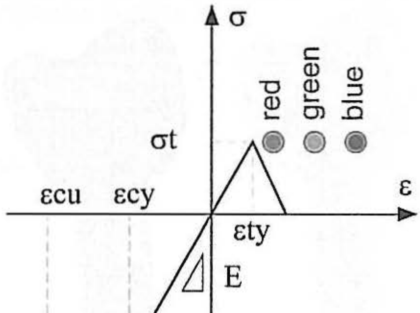


Figure 2. Typical stress—strain relation for ceramic material.

Table 1. Material properties for ceramic material.

Model	Property/Function	Value
Linear (tension/ compression)	Elastic modulus (E)	66.9 [GPa]
	Poisson coefficient	0.29
Non—linear (compression)	STRAIN (ε)	STRESS (σ)
	0	0
	0.005156 (εcy)	345 [MPa]
	0.010000 (εcu)	345 [MPa]
Failure model	Shear transf. coef.	0.25
	(open crack)	0.90
	Shear transf. coef.	120 [MPa]
	(closed crack)	345 [MPa]
	Tensile cracking stress (σt)	1
	Compressive crushing stress (σc).	
	Stiffness mult. for cracked tensile	

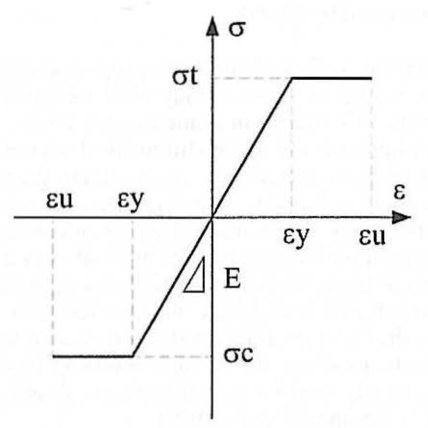


Figure 3. Typical stress—strain relation for titanium.

Material may undergo plastic behaviour under compression. Table 1 represents the linear and nonlinear material properties, together with main parameters of the failure model, based on Willam and Warnke (1975) criterion.

Titanium alloy is considered ductile material, which means that material presents linear elastic and may undergo plastic deformation, under tension and compression, see figure 3. Strain values for ultimate stress may present values close to 20%.

Table 2 represents the material properties for tension and compression of titanium. An elastic and perfect plastic model behaviour is considered.

Table 2. Material properties for titanium alloy material.

Model	Property/Function	Value
Linear (tension/compression)	Elastic modulus (E)	116 [GPa]
	Poisson coefficient	0.34
Non—linear (tension/compression)	Strain (ε)	Stress (σ)
	0	0
	0.002068 (εy)	240 [MPa]
	0.200000 (εu)	240 [MPa]

4 METHOD OF ANALYSIS

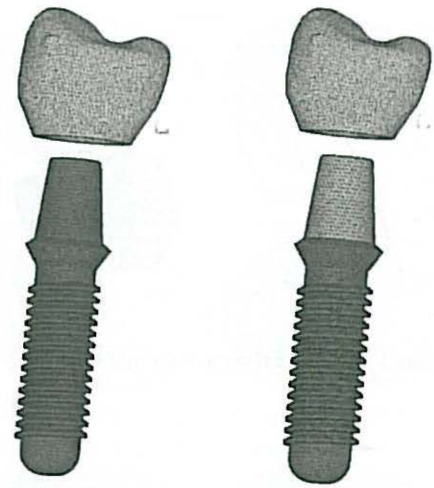
The geometry of this single-tooth implant-supported was defined as parasolid format in Solidworks CAD software and then fully transferred to the analysis ANSYS software. The geometry is mathematically modified using finite solid 65 element and solid 185 element to represent ceramic and metallic material, respectively, see figure 4.

The 3-D solid 65 is capable of cracking in tension and crushing in compression. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. This element is similar to a 3-D structural solid but with the addition of special concept of continuous damage mechanics (smeared approach). This element assumes nonlinear material properties, capable of cracking (in three orthogonal directions), crushing and also undergo plastic deformation. Typical shear transfer coefficients range from 0.0 to 1.0, with 0.0 representing a smooth crack (complete loss of shear transfer) and 1.0 representing a rough crack (no loss of shear transfer). This specification may be made for both the closed and open crack. When the element is cracked or crushed, a small amount of stiffness is added to the element for numerical stability. The stress relaxation is associated with the stiffness multiplier (1) and is only used to help accelerate convergence of the calculations when cracking is imminent, Ansys Inc (2014).

The 3-D solid 185 is normally used for modelling solid structures. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element can take into account plasticity and other material constitutive models.

Two different major models are simulated (model 1 and model 2). Both models present 56462 nodes and 299534 finite elements. Model 1 presents the abutment in titanium, while model 2 presents the abutment in ceramic material.

Large displacement statics is used to solve this numerical simulation, using the arc length solution



a) Model 1 – Abutment in titanium. b) Model 2 – Abutment in ceramic material.

Figure 4. Finite element models to be compared.

method, with a minimum incremental displacement of 0.005 mm and a maximum incremental displacement of 0.25 mm on the cusp zone. The iterative solution accounts for a maximum number of 50 iterations, using the convergence criteria of 0.1 in force.

5 NUMERICAL RESULTS

The nonlinear behaviour of the material on the cusp zone of model 1 is represented in Figure 5. Typical load displacement curve is plotted, allowing to determine the fracture resistance (maximum load) of the single-tooth implant-supported. This model is unable to accommodate the displacement of the loading region due to the higher stiffness of the abutment (titanium).

Figure 6 represents the formation of cracking and crushing in the cusp zone for model 1, where load is increased up to the maximum compressive load (284 N). The extension of damage volume is represented as function of load increments. These load increments are automatic determined, based on the minimum increment of load.

The post processing of cracking and crushing is made with circles at locations of damage in ceramic elements. Cracking is represented with a circle outline in the plane of the crack, and crushing is shown with an octahedron outline. If the crack has opened and then closed, the circle outline will have an X through it. Each integration point can crack in up to three different planes. The first crack at an integration point is shown with a red circle outline,

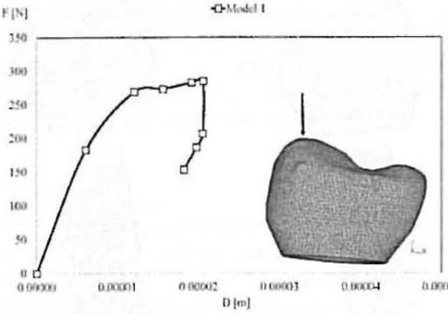
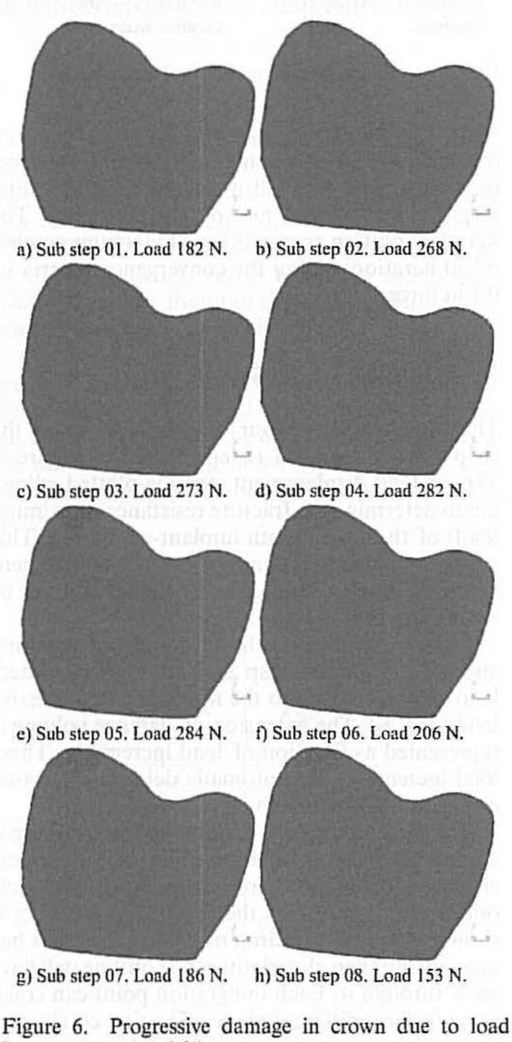


Figure 5. Fracture resistance for model 1.



a) Sub step 01. Load 182 N. b) Sub step 02. Load 268 N.

c) Sub step 03. Load 273 N. d) Sub step 04. Load 282 N.

e) Sub step 05. Load 284 N. f) Sub step 06. Load 206 N.

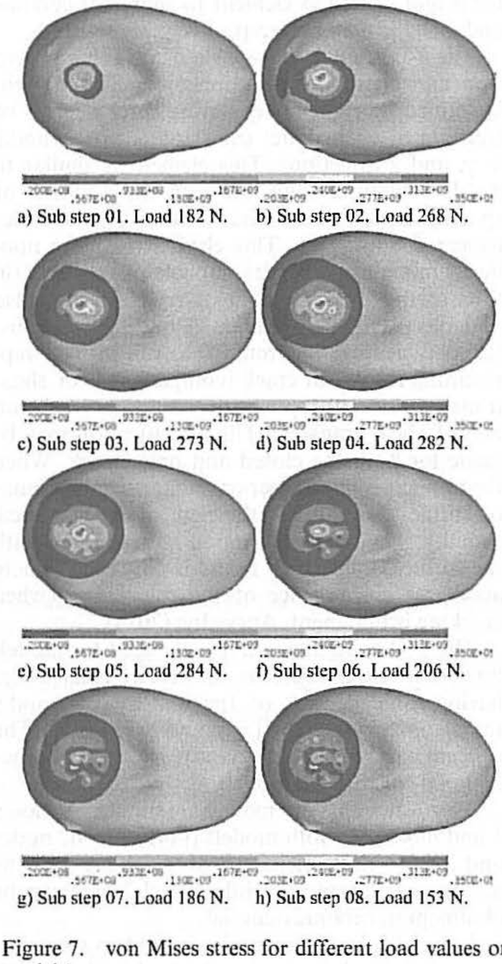
g) Sub step 07. Load 186 N. h) Sub step 08. Load 153 N.

Figure 6. Progressive damage in crown due to load increments on model 1.

the second crack with a green outline, and the third crack with a blue outline.

When both cracking and crushing are used together, care must be taken to apply for small increments of load, preventing fictitious crushing of the concrete before proper load transfer can occur through a closed crack. This usually happens when excessive cracking strains are coupled to the orthogonal uncracked directions through Poisson's effect.

Figure 7 depicts the von Mises Stress for each load increment. The material of the crown starts to initiate fracture before entering in the plastic domain. The stress field increases with load, but starts to be modified as soon as the amount of damage volume increases. Eight sub steps are represented in the von Mises scale, between 20 MPa and 350 MPa. The region with gray colour represents points with equivalent stress smaller than 20 MPa.



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e) Sub step 05. Load 284 N. f) Sub step 06. Load 206 N.

g) Sub step 07. Load 186 N. h) Sub step 08. Load 153 N.

Figure 7. von Mises stress for different load values on model 1.

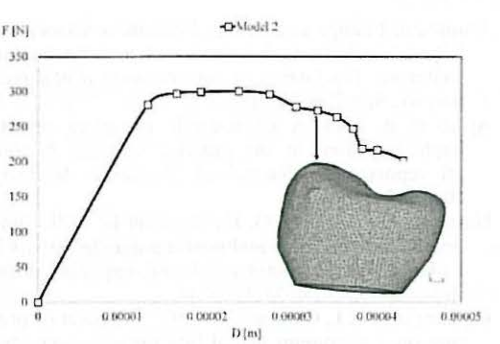
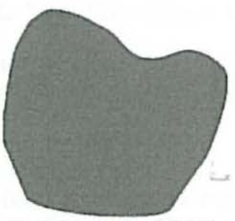
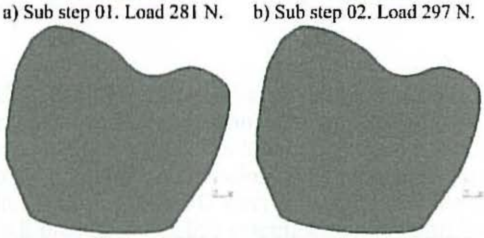


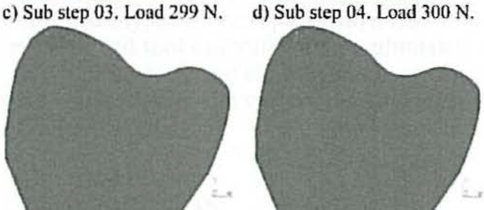
Figure 8. Fracture resistance for model 2.

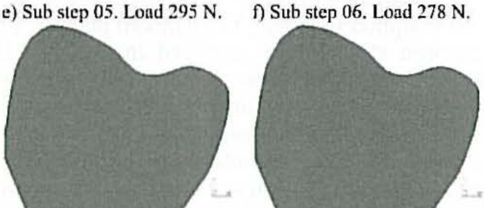
a) Sub step 01. Load 281 N. b) Sub step 02. Load 297 N.



c) Sub step 03. Load 299 N. d) Sub step 04. Load 300 N.

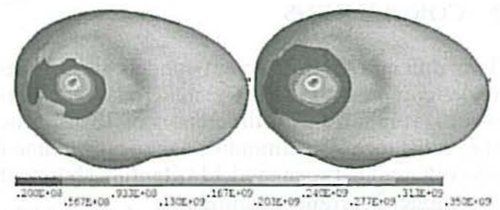


e) Sub step 05. Load 295 N. f) Sub step 06. Load 278 N.

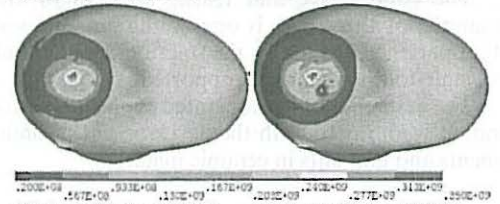


g) Sub step 07. Load 272 N. h) Sub step 08. Load 263 N.

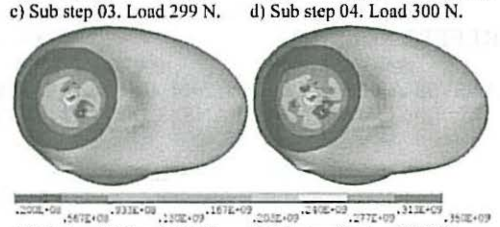
Figure 9. Progressive damage in crown due to load increments on model 2.



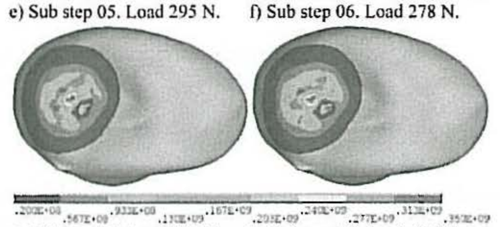
a) Sub step 01. Load 281 N. b) Sub step 02. Load 297 N.



c) Sub step 03. Load 299 N. d) Sub step 04. Load 300 N.



e) Sub step 05. Load 295 N. f) Sub step 06. Load 278 N.



g) Sub step 07. Load 272 N. h) Sub step 08. Load 263 N.

Figure 10. von Mises stress for different load values on model 2.

Figure 8 represents typical load versus displacement on the cusp area of loading for model 2. There is an initial linear behaviour, followed by a nonlinear behaviour, justified by the decrease of resistance due to cracking and crushing. The amount of vertical displacement of the loading area is higher in model 2.

Figure 9 represents the formation of cracking and crushing in the cusp zone for model 2, where load is increased up to the maximum compressive load (300 N).

The extension of damage in the ceramic material is higher for model 2, mainly due to the difference of stiffness of the abutment.

Figure 10 depicts the von Mises Stress for each load increment (sub step). The material of the crown starts to initiate fracture before entering in the plastic domain. The stress field increases with load, maintaining the maximum stress level at the tip of the cracking surface.

6 CONCLUSIONS

Two different finite element models were tested under compressive load. The material of the abutment is responsible for differences of 10% in fracture resistance. The amount of damage volume is also different between model 1 (titanium abutment) and model 2 (ceramic abutment).

The compressive and tensile strength of the material of the crown is one of the most important parameter to access the fracture resistance of a single-tooth implanted-supported.

The aesthetics of an implanted supported restoration is improved with the development of abutments and implants in ceramic material.

REFERENCES

ANSYS® Academic Research. 2014. Release 15.0, *Help System, Element reference*, ANSYS, Inc.

Aramouni, Phillipe et al. 2008. Fracture resistance and failure location of zirconium and metallic implant abutment. *The journal of contemporary dental practice*, vol. 9, n.7, November.

Aydın et al. 2013. A single-tooth, two-piece zirconia implant located in the anterior maxilla: A clinical report, *The Journal of Prosthetic Dentistry*; 109:70–74.

Haraldson T., Carlsson G. E., Ingervall B. 1979. Functional State, bit force and postural muscle activity in patients with osseointegrated oral implant bridges. *Acta Odontol Scan*; 34: 195–206.

Paphangkoravit J., Osborn J.W. 1997. The effect of pressure on a maximum incisal bite force in man. *Arch Oral Biol*; 42: 11–17.

Willam, K.J., and Warnke, E.D. 1975. Constitutive Model for the Triaxial Behavior of Concrete; *Proceedings of International Association for Bridge and Structural Engineering*, Vol. 19, ISMES, Bergamo, Italy, p. 174.

Dentistry is a branch of medicine with its own particularities and very diverse areas of action, which means that it can be considered as an interdisciplinary field. Currently the use of new techniques and technologies is receiving much attention.

BIODENTAL ENGINEERING III contains contributions from 13 countries, which were presented at BIODENTAL 2014, the 3rd International Conference on Biodental Engineering (Póvoa do Varzim, Portugal, 22-23 June 2014). They provide a comprehensive coverage of the state-of-the-art in this area, and address issues on a wide range of topics:

- Aesthetics
- Bioengineering
- Biomaterials
- Biomechanical disorders
- Biomedical devices
- Computational bio-imaging and visualization
- Computational methods
- Dental medicine
- Experimental mechanics
- Signal processing and analysis
- Implantology
- Minimally invasive devices and techniques
- Orthodontics
- Prosthesis and orthosis
- Simulation
- Software development
- Telemedicine
- Tissue engineering
- Virtual reality

BIODENTAL ENGINEERING III will be of interest to academics and others interested and/or involved in biodental engineering.

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