ANGULATED ABUTMENTS AND PERIMPLANTS STRESS: F.E.M. ANALYSIS

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SUMMARY

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The long-term success of an implant supported prosthesis depends on many variables. In addition to the osseointegration rules that are commonly acknowledged, a clinician should consider also the bio-mechanical concepts related to the manufacturing process of a prosthetic structure assembly and their effects on the bone/implant interface. These concepts are particularly important when the anatomical structures leads to angulate the prosthetic component with respect to the fixture. In this study the stress distribution on the bone and on the prosthetic components was evaluated by means of a Finite Element Analysis (FEA). The effect of abutment axis angle was investigated considering three different measures: 15°, 25° and 35°. The simulation of both 450N maximal biting and 100N functional forces, highlighted the stress trend, which suggests as a maximum limit to choose an abutment with an angulation of 25°.

Key words: angulated adutment, dental implant, FEM.

RIASSUNTO

Abutments angolati e tensioni perimplantari: analisi F.E.M.

Il successo a lungo termine di un impianto dentale dipende da numerose variabili. Oltre alle normali regole di osteointegrazione, il clinico deve tenere in considerazione concetti di biomeccanica riguardanti le componenti protesiche che possono influire sulla interfaccia osso impianto. Questi concetti sono molto importanti quando le componenti anatomiche dell'osso residuo necessitano dell'utilizzo di abutment angolati, al fine di parallelizzare le fixture. In questo studio è stata analizzata la distribuzione degli stress al livello dell'osso e delle componenti impianto proteiche tramite l'utilizzo della sistematica FEM (analisi per elementi finiti). Sono stati analizzati tre differenti tipologie di angolazioni: 15°, 25°, 35°; utilizzando due differenti tipologie di carico assiale. Un carico massimo masticatorio di 450N ed un carico funzionale di 100N. Dai risultati ottenuti si evince che il limite massimo di angolazione consigliata è quella a 25°.

Parole chiave: abutment angolati, impianti dentali, FEM.

Introduction

The long-term success of a prosthesis supported by osseointegrated fixtures, relies on the anatomical conditions of the implant site, the surgical technique, the post-surgery bone integration and the distribution of forces during the function (1-3).
The majority of failures are produced by the loss of the bone-implant bond that can occur in any cases immediately after surgery and more frequently at medium and long term.
The biomechanical features have a primary role in the success of an implant-supported fixed prosthesis (4).
Diameter, length, position and number of implants, have significant effects in the stress distribution on the prosthetic superstructure, on the implant components and on the supporting bone (5).
The bone response to mechanical stress has been analysed by several authors, investigating the dy-

namic and adaptive response of the bone component to different load conditions.

The perimplant bone undergoes cyclical load conditions. If the number of cycles are enough in intensity and duration, micro-fractures that stimulate osteoclastic activity may be produced to remove the damaged bone (1, 5).

Rubyn and Lanyon have shown in their studies that the bone is “genetically programmed” to absorb a certain quantity of stress, beyond which remodelling is activated.

The mechanism of this phenomenon and the load threshold to trigger it, have not still been clarified, as it is not yet *evident* whether the absence of load or an excessive load is more harmful to implant success (1-3).

After surgical insertion, implant stability must be preserved not only in the short term post surgery, but also in the long term by means of functional adaptation to stress.

Different studies, on cadavers and animals, have analysed the fixture stability in the bone measuring the torque requested for implant removal, demonstrating how the perimplant bone quality is essential to maintain an implant in a long-term period (5-7).

In an experimental protocol on animals, Soncini et al. (5) have studied the role of surgical technique, proposing a method to evaluate the mechanical properties of the perimplant bone 2mm around the implant, by means of a mechanical pressure assessment.

The forces exerted on the implant-bone component depend on different features: the value of the pressure received, the material that constitute the prosthetic component, the anatomy and the bone quality, the morphology of the fixture and the angle between the implant and superstructure.

Apparently the anatomy of the surgical site, influences the implant insertion and requires a variation of the prosthetic axis, achieved by the use of sloping abutments. The presence of a misalignment between the fixture and the abutment will generate a bending moment that increases the stresses to an high level that can be dangerous for the bone-implant component if it exceeds the allowable values.

The effect of such bending moment is difficult to standardize and has not been sufficiently studied in its critical limits.

According to Ranger, there are two kind of occlusal loading that should be taken into consideration for an implant–supported prosthesis: the axial forces and the lateral-forces, which are the expression of oblique forces.

When these forces are intense, as it happens in angulated abutments, they can trigger a bone resorption phenomenon and/or a loss of bone integration. Furthermore the strength of mechanical components could not be adequate: both effects can concur to implant failure (8).

The purpose of our study is to evaluate the stresses in the implant components, in the prosthetic superstructure and in the perimplant bone, considering different angles between the prosthetic restoration and the implant. To achieve this aim a fine detailed FEM model was developed considering a simplified geometry for the anatomic part and the actual geometry for mechanical components.

Materials and methods

A three-dimensional model of maxillary bone portion in molar region, was built with finite elements (3-D FEM). The finite element technique was first applied to orthodontia analyses in 1976, by Weinstein et al. (9), and successively became one of the most widespread structural surveying methods in the sector, exept for some studies carried out with other numeric techniques having a more limited use (10).

The model was prepared with the Femap 7.0 preprocessor software using the solid modeller.

Cortical and cancellous bone were distinctly represented in the model: the portion of cortical bone consists in 1 mm thick skin located at the external boundary of the solid containing inside the region of cancellous bone. The solid model of the implant with a 5 mm diameter and 10 mm length (Fig. 1a) was inserted in the bone model using Boolean operations *(Premium AF 500 - Sweden & Martina – Bologna Italy)*.

Overall model was constituted by approximately

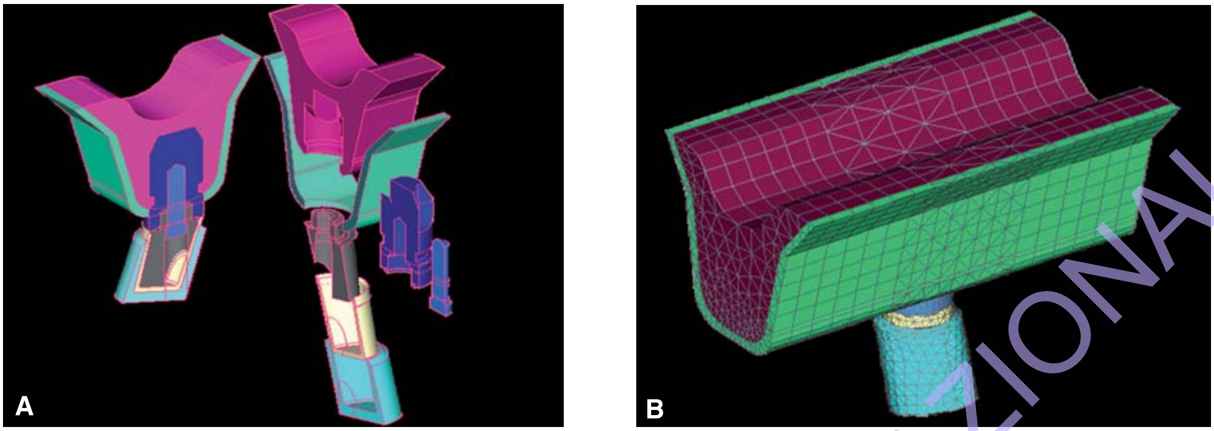

Figure 1
A. Femap 7.5 Model. It's possible to see the entire component: cortical bone, cancellous bone, implant, abutment, screw and crown. **B.** Mesh Model.

41.000 parabolic tetrahedrals and by approximately 23.000 nodes (Fig. 1b).

A linear behaviour was assumed for all the parts considering the mechanical properties Young (E) and Poisson (ν) moduli summarised in Table 1.

Mutually interchangeable abutments with four different types of angulations, 15°, 25°, and 35°, were modelled (Fig. 2).

A simplified crown was made on the abutment; the simplification of the model was required to limit the analised variables only to the angulation of the abutments. Also the mechanical properties of these structures (9-13, 16) are summarised in Table 1.

The medial and distal portions of the maxillary bone model have been blocked by a fixed constraint, to simulate the belonging to the surrounding bone and to the adjacent cranial structures.

In order to verify the correctness of structural model in representing a portion of maxillary bone, a sensitivity study was carried out to determine a transversal dimension of the model that would be large enough to isolate the local effect. A lateral extension of 20 mm of the bone model was found and adopted in the reminder of this study.

Two different axial loads of 100 N and 450 N, were imposed to the crown surface, simulating a normal biting force and maximum chewing stress,

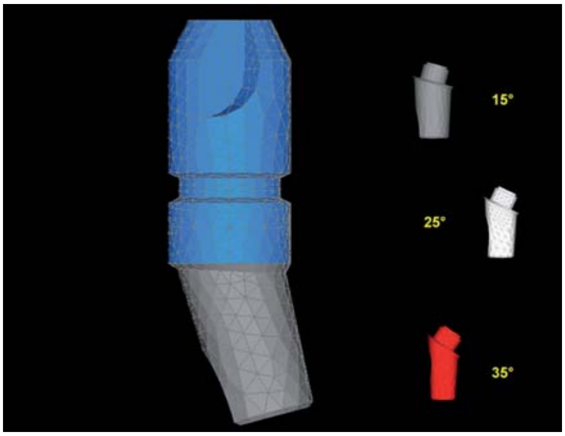

Figure 2
Abutment angulation's: 15°, 25° and 35°.

Table 1 - Mechanical Properties of structural components: E = Young Modulus; ν = Poisson Modulus; G = E/2(1+ν) Shear Modulus.

	E (MPa)	G (MPa)	ν
Implant's Ti	106000	39552	0,34
Gold for Ceramic	110000	41353	0,33
Ceramic	70000	28000	0,25

according to the values recorded in the molar region (14-17).

A pre-load was imposed to the abutment screw. This value was calculated considering a 35 N/cm screwing torque and screw geometry. Such load is produced during screwing down and it is always acting on the system, also in absence of biting loads.

On the whole four FEM models (one for each investigated angle) were prepared for the FEM solver MSC/Nastran 70.5 considering two load levels for each one.

The structural verification of metallic components was conducted assuming a plastic behaviour according to Von Mises criterion. Biologic components integrity was determined on the basis of the maximum shear and maximum compression criteria according to the literature guidelines (18-32).

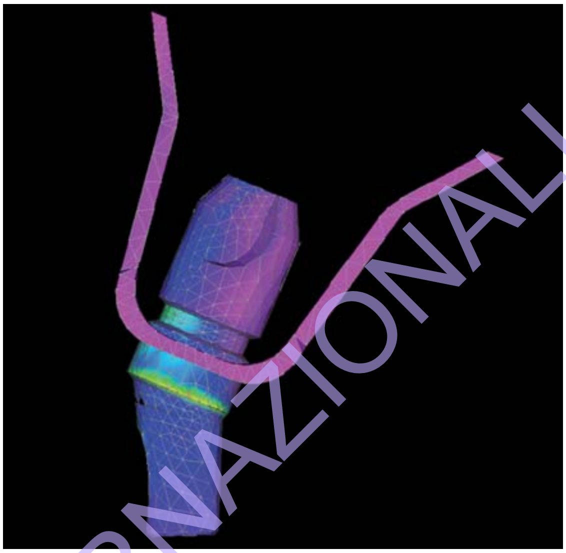

Figure 3
Transversal section, see the vestibular distribution of the stress.

Results

The analysis results show a stress concentration at the level of the interface between the implant collar, the cortical bone and the coronal portion of the cancellous bone, with a localization in the vestibular area, where the higher values of maximum compressive stresses appear (Figs 3, 4).

The stresses peaks have a similar localization whether the angulation or the intensity is changed (100/450N) and their intensity exhibits a growing trend both against load intensity and abutment angulation. Obviously the maximum stress values are observed for the 35° sloped abutment under the maximum load.

The stress peaks obtained on the cancellous and cortical bone components under a functional load of 100 N, are localised at the level of the implant's neck, and have the following values: 3,313 MPa at

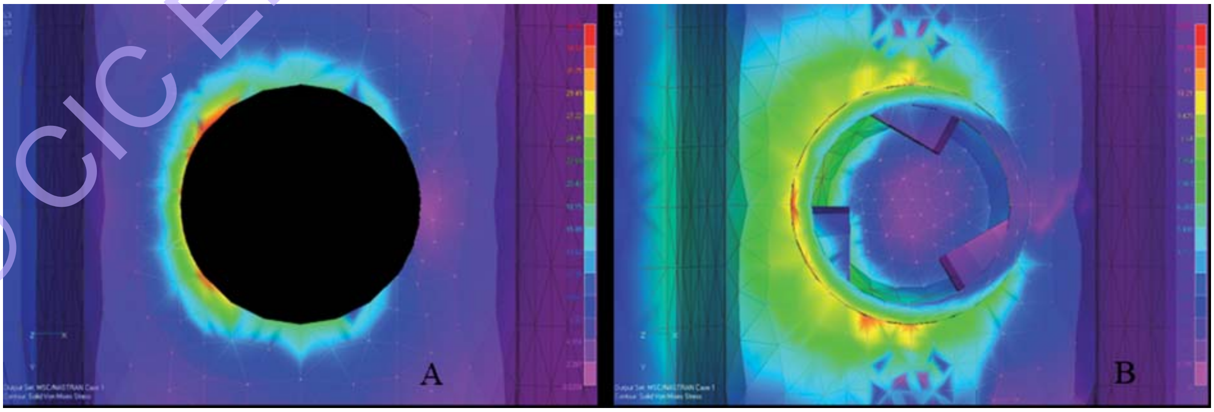

Figure 4
Cortical bone and cancellous bone whit 25° abutment, see the vestibular distribution (**A.** cortical bone **B**. cancellous bone).

15°, 3,977 MPa at 25° and 5,107 MPa at 35° for the cortical component; 2,065 MPa at 15°, 2,627 MPa at 25° and 3,296 MPa at 35° for the cancellous component.

The results obtained with the maximum load are similarly localised and have the following values: 11,23 MPa at 15°, 14,71 MPa at 25° and 28,53 MPa a 35° for the cortical; 7,383 MPa at 15°, 9,961 MPa at 25° and 17,64 MPa at 35° for the cancellous.

For what concerning the implant components, the Von Mises stresses registered under functional loading showed the following result: for the implant 50,83 Mpa at 15°, 50,97 Mpa at 25° and 82,55 Mpa at 35°; for the abutment 127,5 Mpa at 15°, 131,6 Mpa at 25° and 160,1 Mpa at 35°; for the screw 85,58 Mpa at 15°, 89,87 Mpa at 25° and 177 Mpa at 35°.

The values registered under 450N loading have been: for the implant 77,11 Mpa at 15°, 171,3 Mpa at 25° and 118,2 Mpa at 35°; for the abutment 161,4 Mpa at 15°, 194,1 Mpa at 25° and 244,1 Mpa at 35°; for the screw 102,4 Mpa at 15°, 103,4 Mpa at 25° and 188 Mpa at 35°.

It's interesting to notice how the stresses at the level of the cortical and cancellous bone, undergoes a double increase from the 25° angulation to the 35° one (Fig. 5), with a 450N (14,71 MPa, 28,53 MPa; 9,691 MPa and 17,64 MPa).

Discussion

The numerical results obtained from the structural analysis are mathematical calculations so a statistical analysis of the stresses is not required.

As a matter of fact, the current impossibility to simulate the biological response of the tissues to the biting forces, by means of a computerized analysis, limit the reliability of the results obtained from this study, since the normal remodelling or bone resorption subsequent to a traction or compression stimulus cannot be represented.

Anyway obtained results are still useful because the trend of peak stress in the bone represent the severity of the prosthetic structure on the natural tissues. Furthermore structural integrity assessment of mechanical part is mainly related to resultant load and a mechanical failure is expected only if a good bonding and a good mechanical be-

Table 2 - Mechanical Properties of biologic components: E = Young Modulus; ν = Poisson Modulus; G = E/2(1+ν) Shear Modulus; τ = Max Shear Stress; σ_c = Max Tensile Stress.

	E (MPa)	**G (MPa)**	**ν**	**τ (MPa)**	**σ_c (MPa)**
Cortical Bone	13700	5269	0,30	*100*	*173*
Cancellous Bone	7930	3050	0,30	*10*	*17.3*

Table 3 - Stress analysis results in MPa.

		Cortical Bone			**Cancellous Bone**			**Abutment**	**Screw**	**Implant**
	Angulation	**Von Mises**	**Max Prin**	**Min Prin**	**Von Mises**	**Max Prin**	**Min Prin**	**Von Mises**	**Von Mises**	**Von Mises**
Axial Loading 100 N	**Abutment 15°**	9,02	3,133	0,474	3,333	2,065	0,256	127,5	85,58	50,83
	Abutment 25°	11,03	3,977	0,653	4,204	2,627	0,336	131,6	89,87	50,97
	Abutment 35°	13,75	5,107	0,917	4,939	3,296	0,452	160,1	177	82,55
Axial Loading 450 N	**Abutment 15°**	36,29	11,23	2,149	12,57	7,383	1,159	161,4	102,4	77,11
	Abutment 25°	44,98	14,71	2,952	16,22	9,691	1,519	194,1	103,4	171,3
	Abutment 35°	58,96	28,53	5	20,67	17,64	3,681	244,3	188,00	118,2

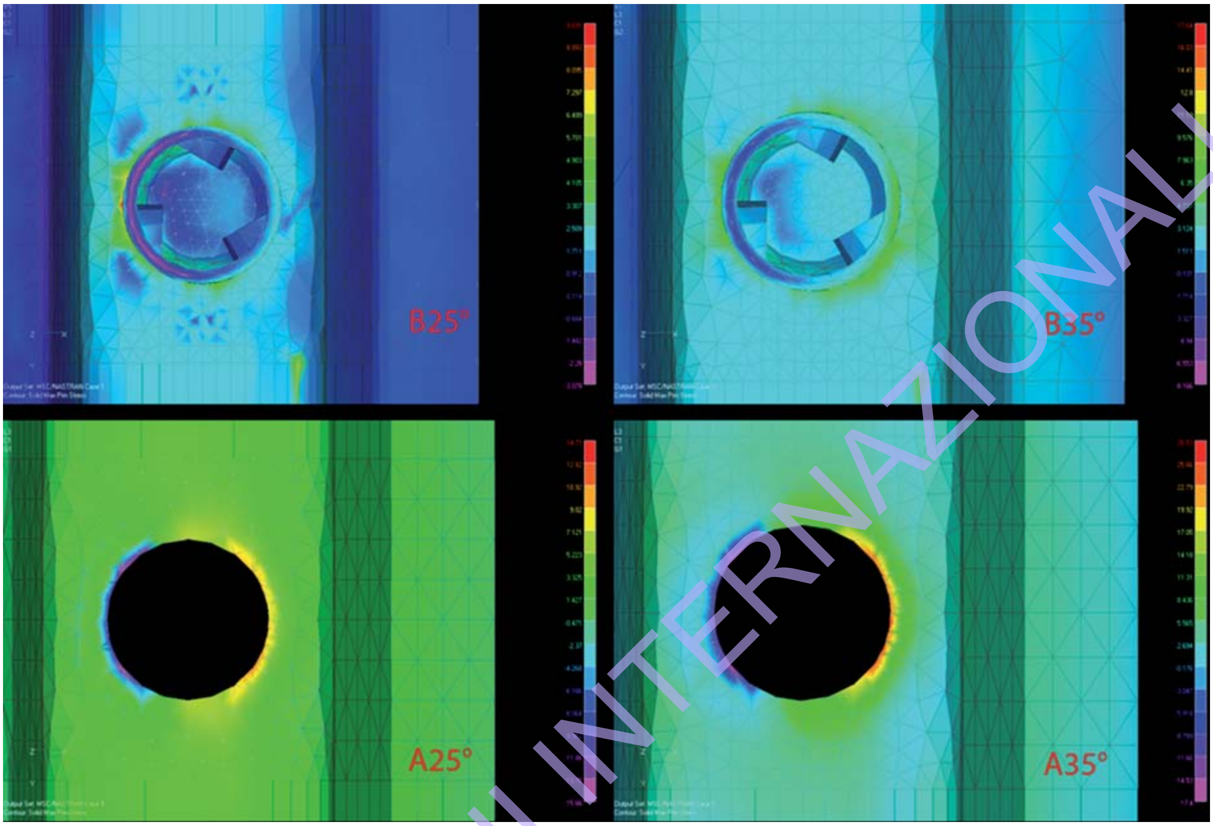

Figure 5
Difference between 25° and 35° abutment on cortical (**A**) and cancellous (**B**) bone. The value undergoes a double increase from the 25° to 35°, with a 450N (14,71 MPa, 28,53 MPa; 9,691 MPa and 17,64 MPa).

haviour is exhibited by the bone. For this reason stress field obtained for metallic component can be used for structural verification.

As previously described for biologic parts maximum shear stress and max compression stress are the critical ones. Their values were confronted with the allowable values that for the cortical bone are respectively 100MPa (Solid Max Shear Stress) and 173 MPa (Solid Min Prin Stress) (32). For the cancellous the values of 10MPa (Solid Max Shear Stress) and 17.3 MPa (Solid Min Prin Stress) were extrapolated from the previous values according to the Young moduli ratio.

In all the analisys (see Tab.2), the values registered in the cortical bone as well as the values registered in the cancellous bone, have been widely below the referenced values. In the cancellous bone with the abutment angulated at 35°, under maximal loading, the referenced limit is achieved. Moreover no study in literature can be found illustrating the stress limits over which a bone resorption process can be started, so it's not possible to state if these values can be considered sufficient or not to start that process.

It is interesting to notice, the linear trend in stress increase, found with a physiological and maximum load, in fact, in the result tables, under 450N, the stresses found were approximately 4,5 times higher respect to those observed with biting loads, remaining almost unvaried in the localizations. This effect is due to the fact that, on the bone, the influence of screw tightening is negligible and therefore, the proportionality of the material's response respect to the external load is evident in the results obtained. While, it is interesting to notice how this had a minor relevance on the screw, whereas the preloading fastening has a significant effect and therefore, the axial components tend to

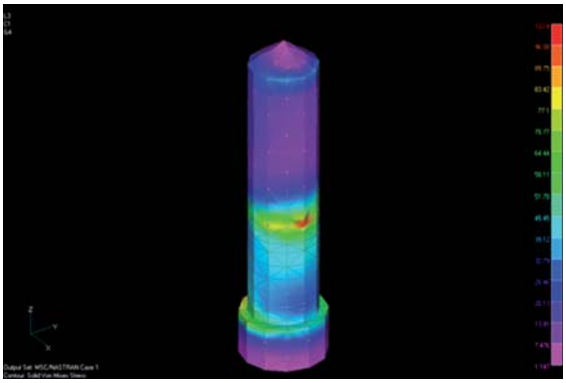

Figure 6
The stress distribution in the screw was localize on the head and the first part of the edging.

shorten the screw, discharging it and setting off loosening phenomenon.

This kind of phenomenon could hesitate in the lost of connection between the fixture and the abutment or in the screw fracture.

What is noticed at last, is the distribution of stresses on the screw, in all condition the stress are localized on the head and the first coil of the screw (Fig. 6).

For what concerning the other model components, abutment, implant and crown, the stress assessed are within the fracture limit of the materials, and this can be observed also in the clinical experience; infact the fracture phenomenon of single implant are very rare.

Conclusions

The results of our studies justify some clinical and radiographic evidence, in which bone resorption was recorded at the level of the implant neck in close contact with the cortical bone.

Structural analyses performed show in this area a concentration of maximum stresses recorded on the bone. These stresses, even if below the maximum limits sustained by the bone structures, seem nonetheless to play a fundamental role in perimplant bone remodelling.

We could affirm that a percentage of the bone resorption (0,2 mm after the 1st year, 0,1 mm for each following year) is due to the healing tissues and the localization of stresses, which are not distributed by the periodontal ligament as it happens in natural teeth.

As far as the use of angulated abutments is concerned, we concluded that, if it is necessary to use them, it is suggested to not exceed the limit of 25°, and if possible to apply them exclusively in the anterior regions, where the forces involved are significantly lower, or whit other implant (full arch). However this study needs confirmations with clinica evaluations.

Bibliografia

1. Rangert B, Jamet T, Jorneus J. Force and moments on Branemark inplants. Int J of Oral and Maxilofacial Implants 1989; 4: 241-247.
2. Lanyon LE. Funcional strain as a determination for bone remodelling. Calcif Tissue International 1984; 36: 56-61.
3. Rubin CT, Lanyon LE. Osteoregulatory nature of meccanical stimuli: function as a determinant for adaptative remodelling in bone. J of Oetop Research 1987; 5: 300.
4. Geng J, Tan KBC, Liu G. Application of finite element analysis in implant dentistry: A review of the literature. J of Prosthetic Dentistry 2001; 85, 6, June, pp. 585-598.
5. Soncini M, Baena RR, Pietrabissa R, et al. Experimental procedure for the evalutation of the mechanical propertis of the bone surrounding dental implants. Biomaterials 2002; 23: 9-17.
6. Papavasiliou G, Kamposiora P, Bayne SC, Felton DA. 3D-FEA of osteointegration percentage and patterns on implant-bone interfacial stress. J Dent 1997; 25: 485-491.
7. Pietrabissa R, Baena RR. Introduzione alla biomeccanica per l'implantologia dentale. Scienza e Tecnica Dentistica Edizioni Internazionali srl, Milano. 2003.
8. Duyck J, Van Oosterwyck H, De Cooman M, Puers R, Vander Sloten J, Naert I. Three-dimensional force measurements on oral implants: a methodological study. J Oral Rehabil 2000 Sep; 27 (9): 744-53.
9. Weinstein AM, Klawitter JJ, Anand SC, Schuessler R, Stress analysis of porous rooted dental implans. J of Dental Rest 1976; 55: 772-777.
10. Citarella R, Esposito R, Infante M. Analisi tensionale di un impianto dentario endosseo con il boundary ele-

ment method (bem). Atti del 32° Conv. Naz. AIAS, Salerno, 2003.
11. Tom WP, Johann AR. Influence of mandibular superstructure shape on implant stresses during simulated posterior biting. The J Prosthet Dent 1999; 82: 67-72.
12. Turner CH, Rho J, Takano Y, Tsui TY, Pharr GM. The elastic properties of trabecular and cortical bone tissues are similar: result from two microscopic measurement techniques. J Biomechanics 1999; 32: 437-441.
13. Teixeira ER, Sato Y, Akagawa Y, Shindoi N. A comparative evalutation of mandibular finite element models with different lengths and elements for implant biomechanics. J Oral Rehabilitation 1998; 25: 299-303.
14. Barbier L, Vander Sloten J et al. Finite element analysis of non-axial versus axial loading of oral implants in the mandible of the dog. J Oral Rehabilitation 1998; 25: 847-858.
15. Sertgoz A. Finite Element analysis study of the effect of superstructure material on stress cistribution in an implant-supported fixed prosthesis. Int J Prosthodont 1997; 10: 19-27.
16. Ichikawa T, Kanitani H et al. Influence of bone qualità on the stress distribution. Clin Oral Impl Res 1997; 8: 18-22.
17. Sertgoz A, Guvener S. Finite element analysis of the effect of cantilever and implant length on stress distributio in an implant-supported fixed prosthesis. J Prosthet Dent 1996; 76: 165-9.
18. Iplikcioglu H, Kivanc Akca K. Comparative evalutation of the effect of diameter, length and number of implant supporting three-unit fixed partialprotheses stress distribution in the bone. J of Dentistry 2002; 30: 41-46.
19. Morgan MJ, James DF. Force and moment distributions among osseointegrated dental implants. J Biomechanics 1995; 28; 9: 1103-1109.
20. Murphy WM, Williams KR, Gregory MC. Stress in bone adjacent to dental implants. J Oral Rehabil 1995; 22: 897-903.
21. Braun S, Johson BE et al. A study of bite force, part 1: relationship to various physical characteristics. Angle Orthod 1995; 65: 5.
22. Rho JY, Ashman RB, Turner CH. Young's modulus of trabecular and cortical bone material: ultrasonic and microtensile measurements. J Biomechanics 1993; 26: 2: 111-9.
23. Jacob HAC, Huggler AH. Biomechanical causes of prosthesis stem loosening. J Biomech 1982; 15: 141-54.
24. Meijer HJA, Kuiper JH, Starmans FJM, Bosman F. Stress distribution around dental implants: influence of superstructure, lengh of implant, and height of mandible. J Prosthet Dent 1992; 68: 96-102.
25. Rieger MR, Brose MO et al. Finite element analysis of bone-adapted and bone-bonded endosseuous implants. J Prosthet Dent 1989; 62: 436-40.
26. Craig RG, El Ebrashi MK, Peyton FA. Experimental stress analysis of dental restauration, part II. Two different photoelastic stress analysis of crowns. J Prosthet Dent 1967; 17: 292.
27. Derand T. Analysis of stress in the porcellain crown. Odont Rev 1974; 25: 189.
28. El Ebrashi MK, Craig RG, Peyton FA. Experimental stress analysis of dental restauration part III. The concept of the geometry of proxymal margins. J Prosthet Dent 1969; 22: 333.
29. Farah JW, Craig RG. Stress analysis of three marginal configurations offull posterir crownby three-dimensional photoelasticity. J Dent Res 1974; 53: 1219.
30. Farah JW, Craig RG. Finite elements analysisof a restored simmetric first molar. J Dent Res 1974; 53: 859.
31. Nally JN, Farah JW, Craig RG. Experimental stress analysis of dental restauration, part IX. Two dimensional photoelastic stress analysisof porcellain bonded to gold crowns. J Prosthe Dent 1971; 25: 307.
32. Papavasiliou G, Petros A et al. Finite element analysis of ceramic abutment restoration combinations for osseointegrated implants. Int J Prosthodont 1996; 9: 254-260.

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