تأثير نوعية العظم في الاجهادات حول الزرعات السنية: دراسة بواسطة تحليل العناصر المنتهية

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الملخص

خلفية البحث وهدفه: إن كثافة العظم لها تأثير واضح في الاندماج العظمي ونجاح الزرعات السنية. الهدف من هذا البحث هو تقييم تأثير أنواع العظم المختلفة في قيم الاجهادات وتوزيعها عند السطح البيني للزرعة والعظم لزرعات التحميل الفوري باستخدام تحليل العناصر المنتهية ثلاثي الابعاد.

مواد البحث وطرائقه: صمم نموذج ثلاثي الأبعاد لزرعة مغروسة في العظم، الزرعة من نوع (LEADER/ITALIA, Fix Type) المصممة خصيصى للتحميل الفوري، استخدم برنامج (ANSYS V.12) لبناء نموذج الزرعة والعظم وإجراء تحليل العناصر المنتهية، كما اعتمد ثلاثة أنواع من العظم، وهي (عظم قشري وعظم نقيوي كثيف وعظم نقيوي قليل الكثافة) وذلك بتغيير خواص عنصر العظم لتشابه خواص الأنواع المختلفة للعظم. طبقت قوة محورية (2 ميكاباسكال) على أعلى الدعامة لتشابه القوى الإطباقية المحورية.

النتائج: أظهرت النتائج أن العظم القشري يتعرض لأقل إجهاد وهو أكثر تنظيماً وتدرجاً للاجتهادات عند السطح البيني للزرعة والعظم من بين أنواع العظم الثلاثة، يليه العظم النقيوي الكثيف، ثم العظم النقيوي قليل الكثافة.

الاستنتاج: إن قيم الإجهاد وتوزيعها عند السطح البيني للزرعة والعظم يتأثر تأثراً كبيراً بنوعية العظم حول الزرعة، إِذْ كلما زادت كثافة العظم قلت قيم الإجهاد وكان توزيع الإجهاد أكثر انتظاماً.

كلمات مفتاحية: زرعات التحميل الفوري، نوعية العظم، تحليل العناصر المنتهية

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The Effect of Bone Quality on Stresses Around Dental Implants: A Finite Element Analysis Study

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Abstract

Background& Objective: the density of bone having an obvious effect on the osseointegration and the success of the dental implants. The aim of the present study is to evaluate the effect of different bone qualities on the values and distribution of stresses at the bone – implant interface of immediately loaded implants by using three-dimensional (3D) finite elements (FE) analysis.

Materials & Methods: A 3-D FE model of an implant embedded in a block of bone was used in this study. The implant was LEADER/ ITALIA-Fix type which is specially designed for immediate loading. ANSYS V.12 program was used to build solid model of the implant and bone, and performing the finite element analysis. Three types of bony tissue(cortical bone, dense trabecular bone, and low density trabecular bone) were used by changing the properties of bone element to simulate the properties of these types. Axially directed force(2MPa) was applied on the top of the abutment to simulate the axial occlusal loading.

Results: The results showed that the cortical bone is subjected to the lowest and most regular and gradual distribution of stresses at the implant-bone interface among the 3 qualities of bone, followed by the dense trabecular bone, then the low density trabecular bone.

Conclusion: This study suggested that the stress values and distribution at the implant-bone interface are greatly affected by the quality of bone around dental implants, that is, when the bone density increased the stress value is decreased and gradually and uniformly distributed.

Key wards: immediate loading implants, bone quality, finite element analysis.

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Introduction:

Dental implants undergo a cascade of biological events at the bone-implant interface leading to bone tissue differentiation and osseointegration(1). As a sequel of intimate and rigid bone-implant contact at the ultra structural level, the bone surrounding implants must function without a stress-reducing element at the interface, such as a periodontal ligament, which exists around natural teeth.(2)

The mechanical distribution of stress occurs primarily where bone is in contact with the implant(3). The quality or density of the bone is directly related to the amount of implant-to bone contact and has been recognized as one of the key factors influencing the long-term success of implants (3,4) . Many researches about single implant success have revealed that bone with high density was demonstrated to have less micro-movement and increased initial stability in single implant fixtures(5). The percentage of bone contact is significantly greater in cortical bone than in trabecular bone. The initial bone density not only provides mechanical immobilization during healing but also permits better distribution and transmission of stresses from the implant-bone interface(3,6). Increased clinical failure rates in poor quality, porous bone, as compared to more dense bone, have been well documented(7) due to thin cortical bone and low-density trabecular bone with poor ability to react properly to the stresses and strains generated by occlusal loads(4). To decrease stress, the clinician may elect to increase the number of implants or use an implant design with greater surface area(3,8,9).

Lekholm and Zarb classification for bone quality has been accepted for evaluating patients for implant placement(10). In this system, the sites are categorized into 1 of 4 groups on the basis of jawbone quality:

Type 1 (D1) bone quality, the entire jaw is comprised of homogenous compact bone.

Type 2 (D2) bone quality, a layer (1.5 mm) of compact bone surrounds a core of dense trabecular bone.

Type 3 (D3) bone quality, a thin layer (0.75mm) of cortical bone surrounds a core of dense trabecular bone.

Type 4 (D4) bone quality, a thin layer (0.75mm) of cortical bone surrounds a core of low-density trabecular bone(3,11).

Three-Dimentional Finite Elements analysis has been widely used for the quantitative evaluation of stresses on the implant and its surrounding bone(12,13). Sevimey et al (2005) stated that there are some investigators studied the influence of the implant design on stress concentration in the bone during loading and indicated that the implant design was a significant factor influencing the stress created in the bone. Others studied the influence of the bone-implant interface on stress concentration. These authors demonstrated that when maximum stress concentration occurs in cortical bone, it is located in the contact area with the implant, while when the maximum stress concentration occurs in trabecular bone, it occurs around the apex of the implant.(14)

Sevimey et al (2005)investigated the effect of 4 different bone qualities (D1, D2, D3, and D4) on stress distribution in an implant-supported mandibular crown, using 3-dimensional finite element (FE) analysis. The results demonstrated that von Mises stresses in D3 and D4 bone qualities were163 MPa and 180 MPa, respectively, and reached the highest values at the neck of the implant. The von Mises stress values in D1 and D2 bone quality were 150 MPa and 152 MPa, respectively, at the neck of the implant. A more homogenous stress distribution was seen in the entire bone. They concluded that stress concentrations in compact bone followed the same distributions as in the D3 bone model, but because the trabecular bone was weaker and less resistant to deformation than the other bone qualities modeled, the stress magnitudes were greatest for D3 and D4 bone.(14)

Li Lin C. et al (2005)(15)study was to evaluate the influence of implant length and bone quality on the biomechanical aspects in alveolar bone and dental implant using non-linear finite element analysis. Frialit-2 root-form titanium implants were buried in 4 types of bone modeled by varying the elastic modulus for cancellous bone. Contact elements were used to simulate the realistic interface fixation within the implant system. The simulated results indicated that the maximum strain values of cortical and cancellous bone increased with lower bone density.(15)

At (2006), Li Lin C et al returned to analyze the biomechanics in a tooth-implant splinting system for various bone qualities with different occlusal forces using non-linear finite element (FE) analysis. A 3D FE model containing one Frialit-2 implant splinted to the mandibular second premolar and a simplified bony segment was constructed. Four bone quality categories were established by varying the elastic parameters assigned to the bone volumes. The results revealed that the maximum stress values on the implants and prosthesis did not exhibit significant differences among the four bone qualities. Conversely, the maximum stress values on alveolar bone increased with reduction in bone quality, especially for type IV bone quality. They concluded that connecting implants with natural teeth should be used with caution in softer bone regions.(4)

The aim of the present study is to evaluate the effect of different bone qualities on the values and distribution of stresses in the bone – implant interface of immediately loaded implants by using three-dimensional (3D) finite elements (FE) analysis.

Materials and Method:

A 3-D FE model of an implant embedded in a block of bone was used in this study. The implant was LEADER/ ITALIA-Fix type which is specially designed for immediate loading(one piece fixture and abutment), the length of implant was 11mm.,the diameter was 3.75mm.fig.(1). The implants was drawn with its real dimensions by AUTO-CAD program. Fig (2)

The 3-D solid finite elements were used to model the bone and implant. The block of bone was 25mm. in height and 15mm. width. ANSYS V.12 program was used to build solid model of the implant and bone, and performing the finite element analysis. Fig (3)

Elements: types and description:

The elements used in the model can be described as follows:

1- Tetanium implant: SOLID9, 3-D 20-Node Structural Solid

SOLID95 Element Description:

SOLID95 is a higher order version of the 3-D 8-node solid element. It can tolerate irregular shapes without as much loss of accuracy. SOLID95 elements have compatible displacement shapes and are well suited to model curved boundaries. SOLID95 has plasticity, creep, stress stiffening, large deflection, and large strain capabilities.

2- The bone: SOLID191, 3-D 20-Node Layered Structural Solid.

SOLID191 Element Description:

SOLID191 is a layered version of the 20-node structural solid (SOLID95) designed to model layered thick shells or solids. The element allows up to 100 different material layers. If more than 100 layers are required, the elements may be stacked. SOLID191 has stress stiffening capabilities.

Bone qualities and Loading:

In this study, 3 types of bony tissue were used which are: cortical bone, dense trabecular bone, and low desity trabecular bone by changing the properties of bone element to simulate the properties of these types. The Elastic modulus and Possion's ratio of the 3 deferent qualities of the bone and the dental implant used in the study are listed in the table (1)

Axially directed force was applied on the top of the abutment to simulate the axial occlusal loading on the implant. The magnitude of force was 2.0 MPa. (16)

Results:

To know the values of von Mises stresses and the pattern of their distribution at the implant-bone interface, see the figures of finite element analysis (4),(5),and(6). Each color in the scale represent a value of stress, the red color represent the maximum value of stress, while the dark blue represent the minimum stress value.

The results of the finite elements analysis on the three qualities of bone in this study shows that the maximum value of von Mises stresses at the bone-implant interface when the bone around dental implant is cortical bone was (1.48MPa) at the cervical area of implant, this value is gradually and regularly decreased as directed apically until reaching the minimum stress value (0.264MPa) at the apex of the implant.fig(4)

In the dense trabecular bone, the maximum von Mises stresses was (11.9MPa) at the apical area of implant, and the lowest value of stresses was at the cervical area (2.31MPa), while the other values were randomly and irregularly distributed along the bone-implant interface.fig(5)

In the low density trabecular bone, the maximum von Mises stresses value was (12.8MPa) at the apical area, and the minimum stress value (2.41MPa) at the cervical area, and the other values were randomly and irregularly scattered along the interface between implant and bone.fig(6)

Discussion:

Micromovement of an endosteal dental implant and excessive stress at the implant-bone interface have been suggested as potential causes for peri-implant bone loss and failure of osseointegration.(14).

A clinical investigation has demonstrated that overload of an implant may result in marginal bone resorption, while the correlation between the poor bone quality and the implant failure has been well established, the precise relationship between bone quality and stress distribution is not adequately understood(14). Consequently, it is valuable to investigate the mechanical responses in bone and their relation to different parameters of implant and bone. However, the biomechanical aspects are difficult to evaluate using clinical observation/experimental approaches with limited information and sample variations. Therefore, finite element analysis has generally been accepted as a complementary tool for understanding the detailed mechanical responses for many biologic investigations.(15)

The accuracy of FE analysis is dependent on the numerical convergence and correctness of the assumptions imposed on the models simulating actual physical conditions, such as boundary and interfacial conditions. Consequently, non-linear contact analysis is needed to mimic a flexible implant system and provide additional information for clinical consideration.(4)

In the present study, an implant- bone model was developed to evaluate the effect of different bone qualities on the stress at the implant-bone interface by means of finite elements analysis:

When comparing the maximum von Mises stress values at the implant-bone interface of the three different bone qualities (Figure7), it can be observed that the cortical bone is subjected to the lowest stress, followed by the dense trabecular bone, while the low density trabecular bone is subjected to the highest value of stress along the contact area between the implant and the bone (i.e) as the density of bone decreased the stress values at the implant-bone interface increased, which denote that the values and distribution of stresses and then the sucsses of dental implants affected by the properties of bone around the implants. This result come in agreement with Sevimey et al (2005)(14), Li Lin C. et al (2005)(15), Li Lin C. et al (2006)(5).but disagree with Kitamura et al (2005)study(17) which found that the stresses may concentrate at the cortical bone more than the spongy bone.

To study the pattern of stress distribution along the implant-bone interface, the FE analysis figures shows that In the first type (cortical bone), the stresses are uniformly and regularly distributed along the interface (i.e) the maximum stress value is at the neck area and decrease gradually until reach the minimum value at the apical area, and this coincide with the results of Yokoyama et al،(2004) (13) and Sevimey et al (2005)(14),whose found that the maximum stresses in the cortical bone are at the neck of implants and more homogenous stress distribution was seen in the entire bone.

In the second type (dense trabecular bone) and the third type (low density trabecular bone), the maximum stresses are mainly concenetrated at the apical area of implant and un uniformly and irregularly distributed along the interface, this may come in agreement with the results of Sevimay et al (2005) study(14)which found that the trabecular bone was weaker and less resistant to deformation than other qualities of bone and when the maximum stress concentration occurs in trabecular bone, it occurs around the apex of the implant.

The difference in the stress values between different bone quality may be due to deference in elasticity (table1)and strain(14).

These results having a great benefit in the clinical applications by instructing the dentist to evaluate carefully the bone quality before deciding whether the case is indicated for implant placement or not.

To complete the evaluations of stresses around dental implants by finite element method, we performed another finite element study to evaluate the effect of implant length and diameter on stress distribution at the implant-bone interface.

Conclusion:

Within the limitations of this FE study, it can be concluded that the stress values at the implant-bone interface are greatly affected by the quality of bone around dental implants, that is, as the density of bone is increase the stress value is decrease. Also, the stress distribution along the implant-bone interface is affected by the quality of bone, (i.e) as the density of bone decrease the values of high stresses directed toward the apex of implant and the stress distribution at the implant-bone interface become more random and less regular.

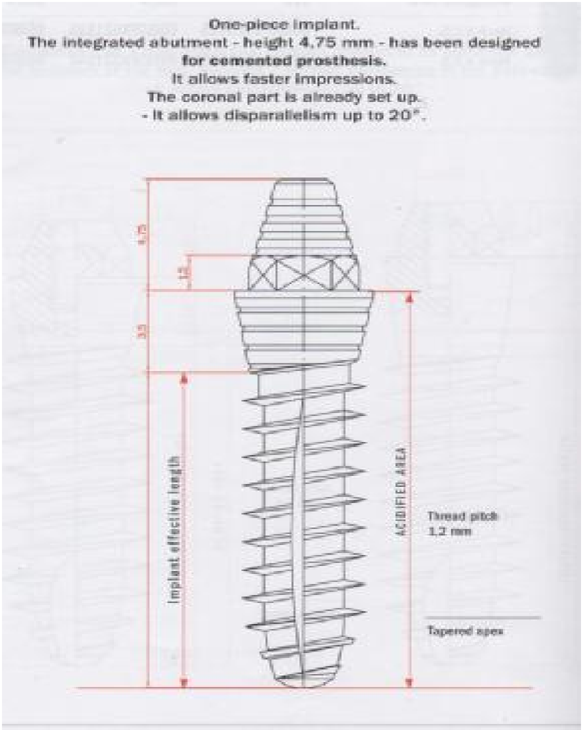

Figure (1) LEADER/ITALIA - Fix Type implant

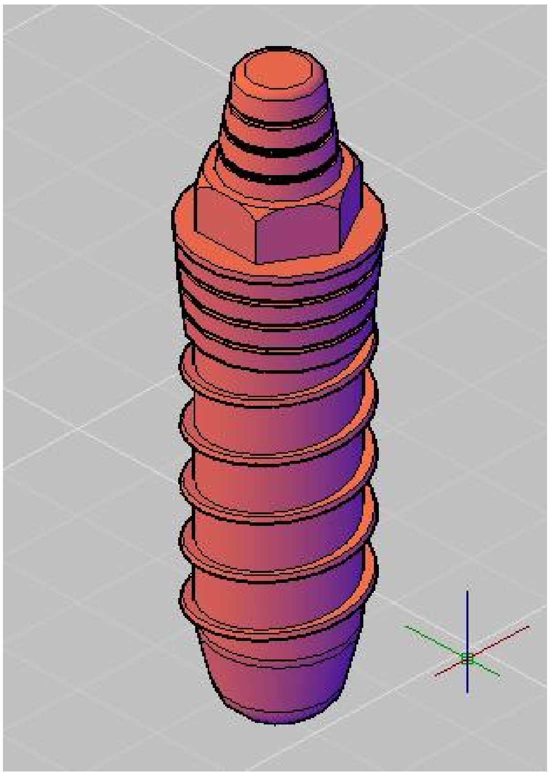

Figure (2) the implant drawn by 3-D AUTO/CAD

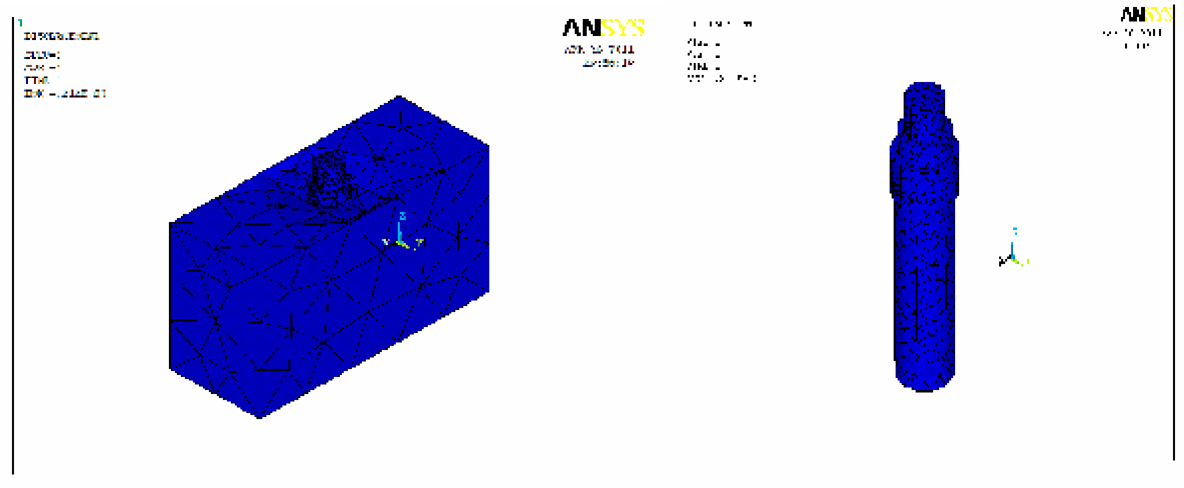

Figure (3) A 3D finite element model of implant and bone block constructed by ANSYS for analysis

Table (1). Material properties of dental implant and the three qualities of bone tissues(4)

Material	Elastic Modulus MPa	Possion's Ratio
Titanium Implant	110000	0.35
Cortical Bone	14800	0.3
Dense Trabecular Bone	1850	0.3
Lower Density Trabecular Bone	231	0.3

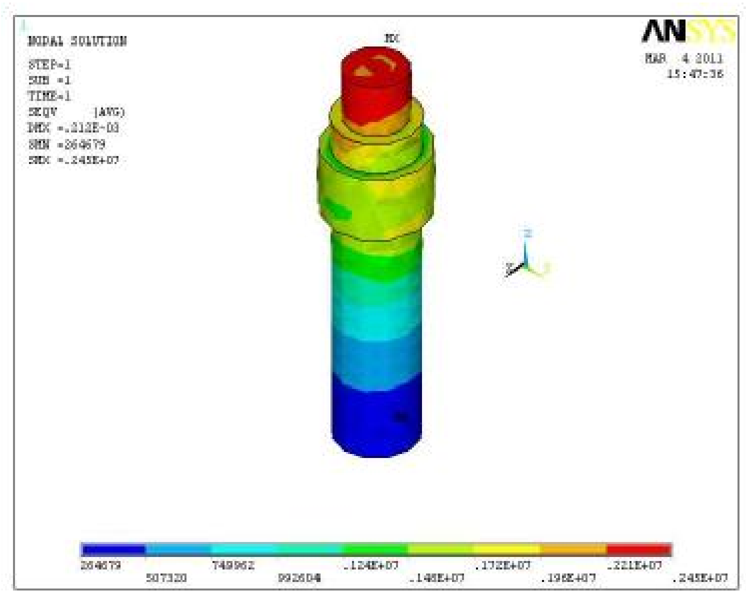

Figure (4) stress values and distribution along implant-bone interface, the bone around implant is (Cortical bone).

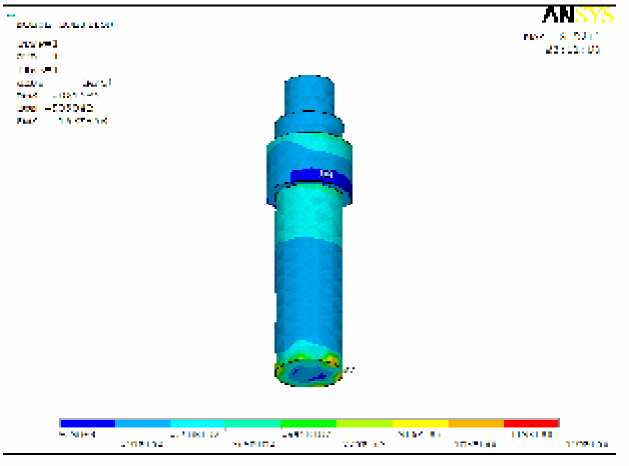

Figure (5) stress values and distribution along implant-bone interface, the bone around implant is (Dense trabecular bone).

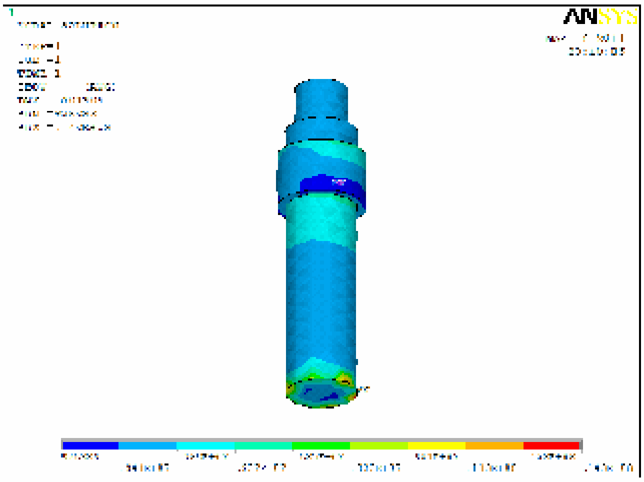

Figure (6) stress values and distribution along implant-bone interface, the bone around implant is (Low density trabecular bone).

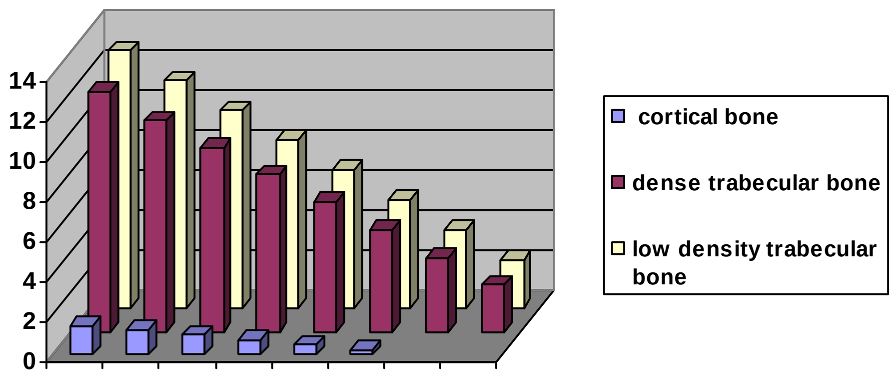

Figure (7) Diagram showing the stress values of the three bone qualities

References

1 - Albrektsson T. and Johansson C. Osteoinduction, osteoconduction and osseointegration. Eur Spine J 2001;(10):96-101.

2 - Hekimoglu C. et al. Analysis of strain around endosseous dental implants opposing natural teeth or implants. J Prosthet Dent 2004;(92):441-6.

3 - Misch CE. Density of bone: effect on treatment plans , surgical approach, healing, and progressive bone loading. Int J Oral Implantol 1990;(6):23-31.

4 - Li Lin C.et al, Finite element analysis of biomechanical interactions of a tooth-implant splinting system for various bone qualities. Chang Gung Med J 2006;(29):143-53.

5 - Holmes D. and Loftus J. Influence of bone quality on stress distribution for endosseous implants. J Oral Implantol 1997;(23):104-11.

6 - Jaffin R. and Berman C. The excessive loss of Branemark fixtures in type IV bone: a 5-year analysis. J Periodontol 1991;62:2-4.

7 - Sato Y.et al, The effectiveness of element downsizing on a three-dimensional finite element model of bone trabeculae in implant biomechanics. J Oral Rehabil 1999;(26):288-91.

8 - Sahin S. et al, The influence of functional forces on the biomechanics of implant-supported prostheses– a review. J Dent 2002;(30):271-82.

9 - Lutfi Koca O. Three-dimensional finite-element analysis of functional stresses in different bone locations produced by implants placed in the maxillary posterior region of the sinus floor J Prosthet Dent 2005;(93):38-44.

10 - Lekholm U. and Zarb GA. Tissue-integrated prostheses. In: Branemark PI, Zarb GA, Albrektsson T(edi): Tissue-integrated prostheses. Chicago: Quintessence 1985;199-209.

11 - Hutton JE. et al. Factors related to success and failure rates at 3-year follow-up in a multicenter study of overdentures supported by Branemark implants. Int J Oral Maxillofac Implants 1995;(10):33-42.

12 - Eskitascioglu G, et al. The influence of occlusal loading location on stresses transferred to implant-supported prostheses and supporting bone: A three-dimensional finite element study. J Prosthet Dent 2004;(91):144-50.

13 - Yokoyama S. et al. The influence of implant location and length on stress distribution for three-unit implantsupported posterior cantilever fixed partial dentures. J Prosthet Dent 2004;(91):234-40.

14 - Sevimay M. et al Three-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown J Prosthet Dent 2005;(93):227-34.

15 – Li Lin C. et al. Effects of dental implant length and bone quality on biomechanical responses in bone around implants: A 3-D non-linear finite element analysis. Biomed Eng Appl Basis Comm 2005;17(1): 44-49.

16- مراد ، محمد لؤي: دراسة تأثير انحراف محور التعويض على نجاح الزرعات السنية ، رسالة دكتوراه ، جامعة دمشق-كلية طب الأسنان،2006: 77-79

17 – Kitamura,E. et al. Influence of marginal bone resorption on stress around an implant-a three- dimensional finite element analysis. J Oral Rehabil 2005;32(4):279-86.

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