JISSE
ISSN: 2636-4425

Journal of International Society for Science and Engineering
Vol. 3, No. 2, 18-24 (2021)

JISSE
E-ISSN:2682-3438

ANGULATED DENTAL IMPLANT VERSUS VERTICAL ONE FINITE ELEMENT STUDY

Ghada Hamza[1*], Mohamed El-Zawahry[1], Hisham ElGabry[1], Mohamed El-Anwar[2]

[1]Fixed and Removable Prosthodontics Dept., National Research Centre, Egypt,

[2]Mechanical Engineering Dept., National Research Centre, Egypt.

ARTICLE INFO

Article history:
Received:2021-03-30
Accepted:2021-04-24
Online:2021-04-24

Keywords:
Finite Element Analysis (FEA)
Molar
Crown
Angled implant

ABSTRACT

Aim: *The aim of this study is to evaluate the effect of different implant angulations under different crown materials on surrounding bone stress distribution using finite element.*
Methods*: Two simplified models were prepared for molar crown supported by implant placed vertically and tilted 25° in simplified mandibular bone geometry. Geometric models' components were prepared on Autodesk Inventor then assembled in ANSYS for finite element analysis. Each model was subjected to two loading cases as 150N compressive load at central fossa and 50N oblique load at mesio-buccal cusp tip.*
Results: *The values of total deformations and Von Mises stresses showed minor difference when changing load position and angle. On the other hand, crown and cement were considerably affected by crown material selection. Also, results showed insensitivity of mucosa, implant complex, cortical and cancellous bone to changing crown material.*
Conclusion: *It was found that the implant complex and bone are showing jump in values of stresses and deformations by changing implant angle and/or loading position and angle. While crown and cement stresses decreased with decreasing crown material rigidity leading to better load distribution at bone implant interface. Implant fixture, mucosa, cortical and cancellous bone were not sensitive to crown material.*

1. Introduction:

Socio economic evolution has speed up the widespread aging of people, that dental prostheses have become essential for enhancing the life quality. [1–3] Dental implantation serves as a foundation for the support of a single-implant supported crowns, fixed or removable prosthesis in partially edentulous areas with satisfactory clinical effect and high long-term success rate. [4]

Despite dental implants were recognized as an excellent mean for substitution of missing teeth, the height of bone may be insufficient for vertical implant placement.

Ideally, the implants should be positioned parallel to the adjacent teeth and aligned vertically with the axial forces. Brånemark System denotes that implant are placed in a fairly upright position in atrophied edentulous areas; in order to provide the patient with good chewing capacity in molar regions, so a bilateral cantilever of about 20 mm in length is essential to be fabricated with such implant position. [5,6]

However, it may not be possible for anatomical reasons. The proximity of dental implants to anatomic structures such as the maxillary sinus or the inferior alveolar nerve, mandibular canal position, crest anatomy, are other factors that can affect implant placement. [7,8] These aforementioned factors, often prevents placement of long (> 10 mm) implants in the posterior areas of the resorbed maxilla and mandible. [9,10]

Various procedures have been suggested to get over these anatomic limitations. Tilting implants are effective and safe substitute.

Some researchers have suggested that tilted implants be used to obtain adequate primary stability [11], with the posterior

---

[*] Ghada Hamza, Fixed and Removable Prosthodontics Dept., National Research Centre, Cairo, Egypt, +201006077362, ghadaezzat22@gmail.com

implants being tilted distally to avoid encroachment on the inferior alveolar neurovascular bundle [6]. The utilization of tilted implants to be aligned parallel to the inferior alveolar nerve, anterior wall of the maxillary sinus or the mental foramen has been suggested as an alternative solution for the management of the atrophied edentulous sites. [12-14] The usage of distally inclined implants reduces the cantilever length and consequently lead to better stress distribution of the prosthetic support.

Moreover, tilted implants can maximize the anterior/ posterior distribution of implants along the alveolar crest to provide sufficient molar support for a multi-unit fixed prosthesis.

The tilting may also allow the use of a more posterior implant position, longer implant and better implant anchorage as well as making use of the cortical bone of the nasal fossa and the wall of the sinus.

Currently, the analysis of characteristics, location, and number of implants; as well as the degree of implant angulation and the cantilever beam with the 3D finite element analysis FEA, has become extremely interesting. FEA results showed that the use of straight implants contributes to the lowest stresses, while bone resorption and higher stress concentrations have been reported in the cortical bone around excessively inclined implants [15,16]; conversely, other studies have reported lower stress concentrations at the crestal region of tilted implants. [15] Clinical studies have demonstrated similar survival rates for straight and tilted implants. [17,18]

The natural teeth are visco- elastically supported in the bone by the periodontal ligament which acts as a shock absorber between a root and encircling bone. On the contrary, there is no periodontal ligament between dental implants and their surrounding bone as in natural teeth. The occlusal loads are transferred directly to adjacent bone which might lead to micro fracture in the interface between implant and bone or implant fracture. [9,10] One of the factors that affect load transfer at the bone implant interface, that influences stress distribution in dental implants and consequently affects morphology of the surrounding bone is the type of prosthetic material.

Selection of crown material should be based on patient bone status. Load transfer and stress distribution at the implant- bone interface is significantly affected by restorative materials. Besides all-ceramic materials; cast gold alloy, porcelain fused to metal, and ceramic-filled polymer crowns [19,20] are being routinely used in clinical practice.

Crown materials with high modulus of elasticity as Zirconia and ceramic crowns transfer high values of the applied load to underlying bone, while crown materials with lower modulus of elasticity reduce the transferred forces to bone than Zirconia [21]. Lower elastic modulus crown material absorbs maximum energy from the applied load, and transfers minimum energy to the underlying system. In other words, occlusal material with low rigidity, will damp the strong occlusal forces, thus decreasing its influence on the implant bone interface. [22]

Zirconia-based ceramics are one of the latest, current, and widely applied ceramics in the advanced dental field. Zirconia has superior mechanical properties [23] as hardness, flexural strength, compression resistance, toughness, corrosion resistance, elastic modulus, biocompatibility, and good soft tissue stabilization. [24-27]

It has been highly recommended to be used in patients with limited inter-occlusal clearance because of its ability to resist high loads with minimum 0.5 mm occlusal thickness. [25,27] The mechanical properties of zirconia allowed them to be used in posterior fixed partial prostheses and significantly reduce the thickness of the cores. [23]

All ceramic crowns were preferred by most patients to porcelain fused to metal crowns due to excellent esthetics, chemical durability and biocompatibility. [28] On the other hand, it has been documented that cast gold alloy crowns have the best longevity of all fixed restorations. [29,30]

Crown material of implant superstructure is a critical factor in the amount and transfer of stresses throughout the implant system under functional load.

The porcelain material effect on stress transfer throughout the implant system under dynamic load applied in vertical and lateral directions was investigated by Eskitascıoglu et al., (1996). Porcelain distributes the stress in its structure and transfer less stresses to implant and surrounding bone. [31]

Ismail et al., (1989) investigated the effect of the crown superstructure materials (porcelain, non-precious, precious alloy, and acrylic or composite resin) throughout the stress in implant and bone, and they reported similar results for all the analyzed materials. [32]

In an investigation, it was reported that porcelain fused to base metal (149 MPa) crown materials had higher von Mises stresses within the metal framework than porcelain fused to noble metal (108 MPa) and IPS Empress 2 (119 MPa) crown martials. [32]

Finite element analyses in vitro studies are simpler and cheaper than clinical trials and provide relatively quicker results in comparison to randomized controlled trials. [30] FEA has been used to analytically solve problems involving complicated geometric forms. [29]

This study aimed to evaluate the effect of implant angulation under different crown materials on surrounding bone stresses and deformations' distributions by finite element analysis.

2. **Materials and Methods**

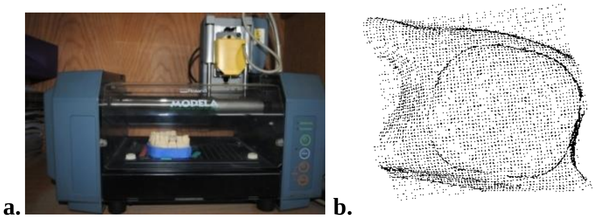
This in-vitro study simulated a clinical situation where a dental implant was placed into mandibular bone in two different ways as; the implant was placed vertically (case study #1) and tilted by 25° inside the bone (case study #2). Titanium implant submerged internal hexed (TUT-II of 13mm length and 4.5mm diameter), hexed superstructure of 3.5mm diameter with fixation screw cosmetic and angled of 10 and 12mm height respectively were used. Thus, two finite element models were specially prepared for this study.

Molar crown geometry was acquired by using 3D scanner (Roland Modela - model MDX-15 - Roland DG Corporation of Hamamatsu, Japan) and computer graphics program (Roland´s Dr. PICZA 3™ software), utilizing Roland Active Piezoelectric Sensor as presented. Such scanner produced data file containing a cloud of points coordinates (Figure 1). An intermediate, software was required (Rhino 3.0 - McNeel inc., Seattle, WA, USA) to trim a newly created surface by the acquired points, that was divided into two parts, lower part (not required), and upper part represented the crown surface. Finally, the crown outer surface was closed and filled from its bottom to generate volume representing solid crown.

The finite element models' components as abutments, cement layer of 50 µm, screw, implant, simplified cortical and cancellous bones were created on “Autodesk Inventor” Version 8 (Autodesk Inc., San Rafael, CA, USA) as presented in Figure 1. These components were exported as STEP files **[4]**, then assembled in ANSYS Workbench environment (ANSYS Inc., Canonsburg, PA, USA). Where all used materials were assumed to be isotropic, homogenous, and linearly elastic and its properties are listed in Table 1.

Table 1: Material properties of used in the finite element model(s)

Material	Young's modules [MPa]	Poisson's ratio
1. Crown Zirconia	210.73	0.34
2. Crown coating Porcelain	68.0	0.35
Crown Ni-Cr	249.0	0.32
3. Crown (gold alloy)	95.0	0.30
Cement Resin	4.04	0.30
Mucosa	0.34	0.45
Implant abutment complex	110.0	0.34
Cortical bone	13.7	0.30
Cancellous bone	1.37	0.30



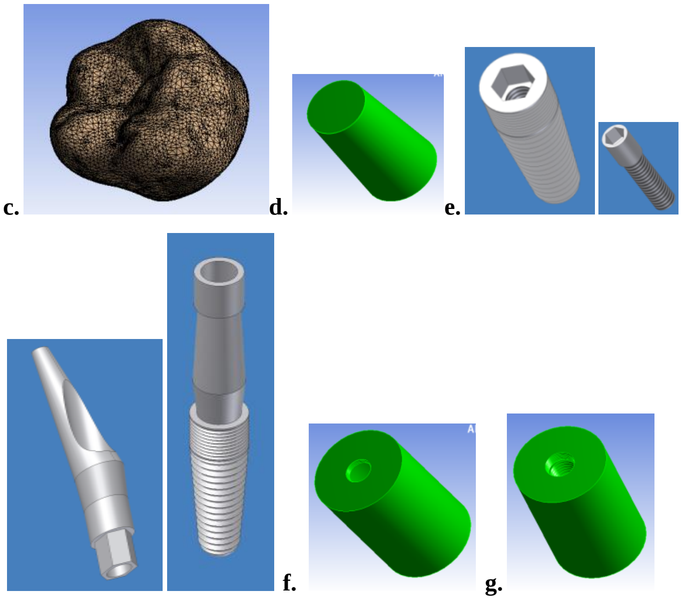


Figure 1: Screen shots of the two models' components during creation of geometric models

Set of Boolean operations between the modeled components were performed before obtaining the complete model(s) assembled. After meshing the resulted numbers of nodes and elements are listed in Table 2 and cut sections in the meshed models are presented as screen shots from ANSYS in Figure 2.

Table 2: Number of nodes and elements in all meshed components

Volume	Vertical Implant Model (Case #1)		Tilted Implant Model (Case #2)	
	Number of Nodes	Number of Elements	Number of Nodes	Number of Elements
Crown	312,329	221,056	329,821	234,857
Cement	35,625	17,679	11,505	5,656
Abutment	4,669	2,290	3,507	1,757
Screw	17,347	10,663	17,713	10,928
Implant	45,469	30,209	45,736	30,421
Cortical bone	25,122	13,091	38,666	22,177
Cancellous bone	75,632	52,260	76,717	52,775
Mucosa	9,543	1,900	10,271	6,377

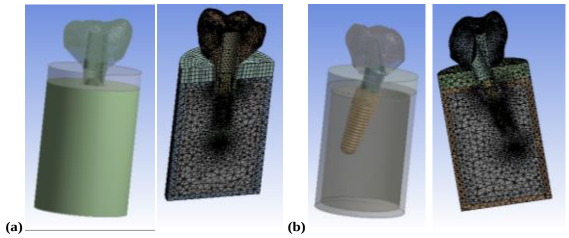


Figure 2: screen shots of cut sections in the two models

The lowest area of the cortical bone was set to be fixed in place as a boundary condition, while the applied compressive load was set to be 150N at central fossa and oblique load of 50N at the mesiobuccal cusp tip. Solid modeling and finite element Linear static analysis was performed on a Workstation HP Z820 (Dual Intel Xeon E5-2670 v2 processors, 2.5 GHz, 64.0 GB RAM), using commercial multipurpose finite element software package (ANSYS version 16.0), then results of these models were verified against similar studies **[5-7]**, and showed good agreement.

3. Results:

All values of total deformations and Von Mises stresses that appeared on both models were within physiological limit under applied loads, where few exceptions were recorded on crown stresses. Sample of the obtained distributions of total deformation and Von Mises stress are demonstrated in Figure 3, while comparisons in Figure 4 may help in extracting conclusions. Concentration of Von Mises stress was noticed on crown surface under points of load application.

Changing crown material did not change deformation or stress distributions significantly, although the Von Mises stress values were slightly varied.

Comparing results showed insensitivity of mucosa, implant complex, cortical and cancellous bone to changing crown material, while minor difference was recorded with changing load position and angle.

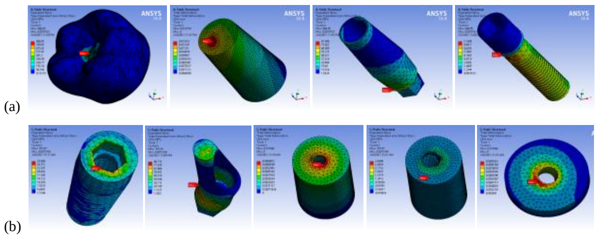


Figure 3: Sample of Von Mises stress and total deformation distributions on the both case studies under compressive load of 150N; (a) vertical implant (b) angulated implant.

On the other hand, crown and cement were considerably affected by crown material selection (Figure 4). Zirconia (520 MPa) crowns induced higher Von Mises stress values within the implant system than porcelain fused to metal (414MPa) and Gold (300 MPa) crowns.

Figure 4: Total deformation and Von Mises extreme values comparison; (a)crown, (b) cement, (c) abutment, and (d) screw.

Titanium parts (abutment and screw) showed step in stresses and deformation values averagely of order 15% with inclined implant system, while each system was insensitive to crown material selection. On the other hand, Von Mises stresses decreased in the implant bone interface around implant tilted by 25° compared to the vertical one.

4. Discussion:

Dental implant is well noted as an anticipated replacement for partially edentulous areas. Unfortunately, the substitution of missing teeth with long endosseous implants in the posterior regions is usually accompanied with anatomic limitations such as the presence of maxillary sinuses, mandibular canal, poor bone quality and bone resorption. Various procedures have been suggested to get over these anatomic problems. The utilization of tilted implants to be aligned parallel to the mandibular canal or the anterior wall of the maxillary sinus has been suggested as an acceptable solution for the management of the resorbed edentulous sites.

FEA method has several advantages, such as being cheaper, permitting standardized samples and having limited variables affecting the results **[36]**. Moreover, it allows simulation of bone tissues with similar properties as *in vivo* tissues.

Abutment and screw play critical role in transferring loads to underneath structures, such that better design might reduce or eliminate crown material, load position and angle effects. Such good implant complex design might show less deformations and stresses in inclined implant system in comparison to straight one.

In the current study, Von Mises stresses decreased in the implant bone interface around implant tilted by 25° compared to the vertical one leading to better stress distribution. Abutment and screw showed rise in stresses and deformation values averagely of order 15% with the inclined implant system.

These results agree with a 3D finite element analysis obtained by Ozan and Kurtulmus- Yilmaz [16] who investigated the impact of degree of angulation of implants (0, 17, 30, and 45°) on distribution of stresses in the implant and the cortical bone of mandible. They found that stress distribution is better when implants are tilted 30° or 45° posteriorly.

Also, Saber et al. [37] investigated the effect of different implant inclinations 0, 15, 30, and 45° on stress distribution around implants in posterior maxillary bone. They concluded that maximum stress reduction in cortical bone was produced by increased posterior implants inclination.

Moreover, Tuncelli et al., (1997) found lower stress concentrations at the crestal region of tilted implants [38]. Furthermore, in a study performed by Liu et al., (2019) two implants were placed tilted bilaterally in the second premolar area at different angles inclinations 15, 30, and 45 degrees under a loading of 150N. They showed that optimal stress reductions were recorded when the distal implants were tilted at 30° [4].

On the other hand, Clelland et al., (1995); Federick et al., (1996); Watanabe et al., (2003) reported bone resorption and higher stress concentrations in the cortical bone around excessively inclined implants 7-8,10. While, Sethi et al.,2000 & 2002; Capelli et al., 2007 demonstrated in clinical studies similar survival rates for straight and tilted implants [39-41].

Tilted implants have several advantages: reduction or avoidance of bone surgery [41], adequate primary stability of long implants, and reduction of stress concentrations at the crestal region. In addition, a work by Soto-Penaloza et al. recorded a survival rate of 99.8% for 24 months in implants [42].

Crown and thin cement layer stresses increased with increasing crown material rigidity, due to stress concentration under loading points. While crown and cement deformations decreased with increasing crown material rigidity. On the other hand, crown and cement stresses decreased with decreasing crown material rigidity leading to better load distribution at the bone implant interface.

In the current study, the analysis of the Von Mises stress values revealed that crown and cement were considerably affected by crown material selection (Figure 4). Zirconia (520 MPa) crowns produced higher von Mises stress values within the implant system than porcelain fused to metal (414MPa) and Gold (300 MPa) crowns. Complete cast gold alloy crowns allowed more amount of stress distribution to the underlying cortical bone and implant, followed by PFM crowns, while zirconia crowns allowed the least amount of stress distribution to the surrounding structures. These findings can be explained by those materials with low young's modulus values (lower rigidity) as gold have the ability to absorb most of the energy from the applied load, which means less energy will be transferred to the next part of the implant system which reduces the stresses generated on the jawbone (cortical and spongy), thus decreases its effect on the bone implant interface [22].

These findings agree with Sara et al., (2016) who estimated the efficiency of several materials with various levels of stiffness on stress distribution in cortical bone and implant. They noticed that crowns of porcelain material (345 MPa) had the maximum von Mises stress values, on the other hand, crown of PEEK material transmit minimum stress to the screw and the abutment. [43]

Moreover, the stress distribution in different porcelain crown materials was investigated by Berge et al., (2001) [44]. For each type of the stress value was different, when investigating the stress distribution in framework. This variation perhaps may be due to that the modulus of elasticity of In-Ceram and porcelain fused to base metal was greater than that of IPS Empress 2 and porcelain fused to noble metal. Because of this greater modulus of elasticity, frameworks of In-Ceram and porcelain fused to base metal were more resistant to deformation. Thus, the stress distribution in the components of the implant system is influenced by the variation in framework structure. [44]

These results also agree with Geng *et al.*, (2001); El-Anwar *et al.*, (2012); and Soliman *et al.*, (2015) who discovered that crown materials with low young's modulus values absorb more energy especially if it has the capability to deform freely. In other words, less energy will be transferred to the next part of the system. In addition, the highest deformation and stresses will appear on the crown and cement layers. Lower rigidity crown received slightly less stresses and higher deformation; in other words, it absorbs more energy than the more rigid one [45,36,46]

In contrary to our results, Bassit *et al.*, (2002) stated that application of various materials in occlusal surface does not lead to various stresses in implants.

Therefore, selection of the crown materials is an important factor in studying the stress exerted over the bone surrounding dental implant. For long-life implants success, a convenient distribution of stresses on a wide region of bone is prioritized (El-Anwar *et al.*, 2012) [36;47].

Abutment and screw absorbed the majority of the applied load energy, thus minimizing the effect of loading on the underneath parts (implant and bone). In other words, implant and cortical bone were not sensitive to crown material due to abutment and screw design.

Due to lacking periodontal ligaments and other soft tissue structures, and the difference in biomechanical behavior between the implant prothesis and bridge support of the natural tooth, in addition to, implanted prothesis are not sensitive to teeth occlusal force; therefore, these factors may result in increasing load and finally failure of restoration. Remarkably, the design of implant is influencing the distribution of stresses on bone [49], demonstrating that the right implant design, including biomechanical design will lead to the implant's success [50, 51].

In this study, there was no considerable change in either deformation or stress distributions but was only slight variation in the values. The results revealed that mucosa, implant complex, cortical and cancellous bone were insensitive to changing crown material. (Figure 4).

This agrees with Hamza et al., (2019) who stated that bone showed no change in stress or deformation by changing the crown material, i.e., bone was insensitive to crown materials. The highest stresses were well below the compressive and tensile bone strength [27].

These finding is in accordance also with Soliman *et al*., (2015) and Wazeh *et al*., (2018), they found that Von Mises stress on jaw bones are not affected by changing crown material [35.46]. This also is augmented by results of a study (de Kok *et al*., 2015) revealing that suitable zirconia implant thickness shows low levels of stress [52].

Also, in an important study, (Güngör *&* Yılmaz, 2016) proving our results, it was found that the bone stresses are not affected by the material of crown [53]. Also, in a study by Moreira et al., (2013) using different materials, no differences were noted when investigating the stress distribution in supporting bone [48].

5. Conclusions:

Within the scope of this study, for well-designed implant complex, especially abutment and screw can do a critical role in saving underneath structures. Implant fixture, mucosa, cortical and cancellous bone were saved from overstressing or failure by well designing abutment and screw. The implant fixture, mucosa, cortical and cancellous bone were not sensitive to crown material, while implant complex and bone showed jump (step) in values of stresses and deformations by changing implant angle and/or loading position and angle. Abutment and connection screw design are responsible for this step (jump) with changing implant angle. Crown and cement stresses increase with crown rigidity, while deformations decrease. On the other hand, crown and cement stresses decreased with decreasing crown material rigidity leading to better load distribution at the bone implant interface.

ETHICAL APPROVAL:

This research doesn't require ethical approval and followed the Helsinki declaration.

The authors declare that they have no conflict of interest.

References

[1] E. L. Agliardi, L. Francetti, D. Romeo, and M. Del Fabbro,"Immediate rehabilitation of the edentulous maxilla: preliminary results of a single cohort prospective study," International Journal of oral & Maxillofacial Implants, vol. **24**, no. 5, pp. 887–895, 2009.

[2] E. Agliardi, M. Cleric`o, P. Ciancio, and D. Massironi, "Immediate loading of full-arch fixed prostheses supported by axial and tilted implants for the treatment of edentulous atrophic mandibles," Quintessence International, vol. **41**, no. 4, pp. 285–293, 2010.

[3] E. Agliardi, S. Panigatti, M. Cleric`o, C. Villa, and P. Mal`o, "Immediate rehabilitation of the edentulous jaws with full fixed prostheses supported by four implants: interim results of a single cohort prospective study," Clinical Oral Implants Research, vol. **21**, no. 5, pp. 459–465, 2010.

[4] X. Liu, F. Pang, Y. Li, H. UiJia, X. Cui, Y. Yue, X. Yang, Q. Yang, "Effects of Different Positions and Angles of Implants in Maxillary Edentulous Jaw on Surrounding Bone Stress under Dynamic Loading: A Three-Dimensional Finite Element Analysis," Computational and Mathematical Methods in Medicine, 1-9, 2019.

[5] B. Rangert, T. Jemt, L. Jörneus, "Forces and moments on Brånemark implants", Int J Oral Maxillofac Implants; vol. **4**, pp. 241-247, 1989.

[6] A. Sertgöz, S. Güvener, "Finite element analysis of the effect of cantilever and implant length on stress distribution in an implant-supported fixed prosthesis," J Prosthet Dent., vol. **76**, pp. 165-169, 1996.

[7] Z. Arsalanloo, R. Telchi, K. G. Osgouie, "A Three-Dimensional FEA of Implants to Investigate Effects of Angle Implantation Cases in Implants Success", International Journal of Bioscience, Biochemistry and Bioinformatics, vol. **4,** no. 4, pp. 275–279,2014.

[8] D. Buser, W. Martin, U. C. Belser, Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations, International Journal Oral Maxillofacial Implants, vol. 19, pp. 43–61, 2004.

[9] Lídia Carvalho, António Ramos, José A. Simões, "Finite Element Analysis Of A Dental Implant System With An Elastomeric Stress Barrier", In 2003 Summer Bioengineering Conference, Florida,0733-2, USA, 2003.

[10] R. A. Markarian, R. G. Lima, R. M. Souza, C. L. Sendyk," The influence of the prosthetic materials stiffness on load transfer to dental implants". In 2005 Technology Meets Surgery international, São Paulo, SP 2005.

[11] C. Caglar A, Aydin C, Ozen J, "Effects of mesiodistal inclination of implants on stress distribution in implant-supported fixed prostheses", Int J Oral Maxillofac Implants, *vol.* **21**, pp. 36–44, 2006.

[12] L. Krekmanov, M. Kahn, B. Rangert, H. Lindstrom, "Tilting ot posterior mandibular and maxillary implants of improved prosthesis support", Int J Oral Maxiliofac Implants, vol. **15**, pp. 405-414, 2000.

[13] Y. Fortin, RM. Sullivan, BR. Rangert, "The Marius implant bridge: surgical and prosthetic rehabilitation for the completely edentulous upper jaw with moderate to severe resorption: a 5-year retrospective clinical study",Clin Implant Dent Relat Res, vol. **4**, pp. 69-77, 2002.

[14] P. Malò, B. Rangert, M. Nobre, "All-on-Four" immediate-function concept with Brånemark system implants for completely edentulous mandible:A retrospective clinical study", Clin Implant Dent Relat Res vol. **5, no.** 1, pp. 2-9, 2003.

[15] P.I. Branemark, K, Grandahl, L.O. Ohrnell, "Zygomofixture in the management of advanced atrophy of the maxilla: technique and long-term results", Scand J Plast Reconstr Surg. vol. **38, no.** 2, pp. 70-85, 2004.

[16] O. Ozan, Kurtulmus-Yilmaz Sevcan, "Biomechanical Comparison of Different Implant Inclinations and Cantilever Lengths in All-on-4 Treatment Concept by Three-Dimensional Finite Element Analysis", Int J Oral Max Impl. vol. **33, no.**1, pp. 64-71, 2018.

[17] A. Sethi, T. Kaus, P. Sochor, D. Axmann-Krcmar, M. Chanavaz, "Evolution of the concept of angulated abutments in implant dentistry: 14-year clinical data", Implant Dent vol. 11, pp. 41–51, 2002.

[18] M. Capelli, F. Zuffetti, M.D. Fabbro, T. Testori, "Immediate rehabilitation of the completely edentulous jaw with fixed prostheses supported by either upright or tilted implants: A multicenter clinical study", Int J Oral Maxillofac Implants vol. **22**, pp. 639-644, 2007.

[19] F. Bohlsen, M. Kern, 'Clinical outcome of glass fiber reinforced crowns and fixed partial dentures: A three-year retrospective study", Quintessence Int., vol. **34**, pp. 493-6, 2003.

[20] P. Rammelsberg, K. Spiegl, G. Eickemeyer, M. Schmitter, "Clinical performance of metal-free polymer crowns after 3 years in service", J Dent., vol. **33**, pp. 517-23, 2005.

[21] M. Menini, E. Conserva, T. Tealdo, M. Bevilacqua, F. Pera, G. Ravera, et al., "The use of a masticatory robot to analyze the shock absorption capacity of different restorative materials for implant prosthesis", J Biol Res., vol. **134**, pp. 118-9, 2011.

[22] M.I. El-Anwar, M.S. El-Mofty, A.H. Awad, S.A. El-Sheikh, M.M. El-Zawahry, "The effect of using different crown and implant materials on bone stress distribution: a finite element study", EJOMS vol. 5, pp. 58-64, 2014.

[23] Piconi, and G. Maccauro, "Zirconia as a ceramic biomaterial", Biomaterials, vol. **20**: pp. 1-25, 1999.

[24] M. Hisbergues, S. Vendeville and P. Vendeville, "Zirconia: Established facts and perspectives for a biomaterial in dental implantology", J Biomed Mater Res B Appl Biomater, vol. **88**, pp.519-29, 2018.

[25] M.Nevins, M. Camelo, M.L. Nevins, P. Schupbach and D.M. Kim, "Pilot clinical and histologic evaluations of a two-piece zirconia implant", Int J Periodontics Restorative Dent., vol. **31**, pp. 157-63, 2011.

[26] A.M.O.Dal Piva, , L.P.C. Contreras, F.C. Ribeiro, L.C. Anami, S.E.A. Camargo and A.O.C. Jorge et al., "Monolithic ceramics: Effect of finishing techniques on surface properties, bacterial adhesion and cell viability", Oper Dent., vol. **43**, pp. 315-25, 2018.

[27] G.E. Hamza, M. M. El-Zawahry, M. I. El-Anwar, "3D Finite Element Study on Crown and Cement Materials Combination Effect on Implant-Bone Interface Stress Distribution", Curr. Sci. Int., vol. **8, no.** 3, pp. 540-548, 2019.

[28] W.P. Pol-Christian, W. Kalk, "A systematic review of ceramic inlays in posterior teeth: an update", Int. J. Prosthodont. vol. 24, pp. 566–575, 2011.

[29] S.F. Rosenstiel, M.F. Land, J. Fujimoto, "Contemporary Fixed Prosthodontics". 4th ed. St. Louis: Mosby, pp. 209-323, 2007.

[30] G.J. Christensen, "Longevity versus esthetics: The great restorative debate", J Am Dent Assoc, vol. 138, pp.1013-5, 2007.

[31] G. Eskitascıoglu, I. Baran, Y. Aykac, D. Oztas, "Investigation of the effect of different esthetic materials in implant-crown design", Turkish J. Oral Imp,vol. 35, pp. 23-25, 1996.

[32] Y.H. Ismail, S. Kukunas, D. Pipko, W. Ibiary, "Comparative study of various occlusal materials for implant prosthodontics" J Dent Res, vol. **68, pp.** 962-5, 1989.

[33] Al Qahtani W.M.S., Yousief S.A., El-Anwar M.I. Recent Advances in Material and Geometrical Modelling in Dental Applications. Open Access Maced J Med Sci. vol. 6, no. 6, pp. 1138-1144, 2018. DOI: https://doi.org/10.3889/oamjms.2018.254.

[34] Hamed H.A., Marzook H.A., Ghoneem N.E., El-Anwar M.I. Angulated dental implants in posterior maxilla FEA and experimental verification. Open Access Maced J Med Sci. vol. 15; no. 6, pp.397-401, 2018. Doi: 10.3889/oamjms.2018.077

[35] Wazeh AM, El-Anwar MI, Atia RMG, Mahjari RM, Linga SA, Al-Pakistani LMA, Yousief SA. 3D FEA Study On Implant Threading Role on Selection of Implant and Crown Materials. Open Access Maced J Med Sci. vol. 6, no. 9, pp. 1702-1706, 2018. DOI: 10.3889/oamjms.2018.331

[36] El-Anwar, M.I., M.M. El-Zawahry, M.S. El-Mofty. Load transfer on dental implants and surrounding bones. Aust J Basic Appl Sci., vol. 6, pp. 551-60, 2012.

[37] Saber F. S., Ghasemi S., Koodaryan R., Babaloo A., and Abolfazli N., "-e comparison of stress distribution with different implant numbers and inclination angles in all-onfour and conventional methods in maxilla: a finite element analysis," *Journal of Dental Research, Dental Clinics, Dental Prospects*, vol. 9, no. 4, pp. 246–253, 2015.

[38] Tuncelli B, Poyrazoglu E, Koyluoglu AM, et al. Comparison of load transfer by implant abutments of various diameters. *Eur J Prosthodont Restor Dent*. vol. 5, pp. 79–83, 1997.

[39] Clelland NL, Lee JK, Bimbenet OC, Brantley WA. A three-dimensional finite element stress analysis of angled abutments for an implant placed in the anterior maxilla. J Prosthodont. vol. 2, pp. 95–100, 1995.

[40] Federick DR, Caputo AA. Effects of overdenture retention designs and implant orientation on load transfer characteristics. J Prosthet Dent. vol. 76, pp. 624–632, 1996.

[41] Watanabe F, Hata Y, Komatsu S, Fukuda H. Finite element analysis of the influence of implant inclination, loading position, and load direction on stress distribution. Odontology. vol. 91, pp. 31–36, 2003.

[42] Rangert B, Sullivon RM, Jemt T. Load factor control for implants in the posterior partially edentulous segment. Int J Oral Maxillofac Implant. 1987;12(3):360-370.

[42] Tasa S, Strengoiu R, Kitamura E. Influence of implant design and bone quality on stress/strain distribution in bone around implants: a 3-dimensional finite element analysis. Int J Oral Maxillofac Implant. vol. 18, no. 3, pp. 357-368, 2003.

[43] Sara Ahmed Sayed Ahmed; Mohamed A. A. Eldosoky; Mohamed Tarek El-Wakad; Emad MTM Agamy. Effect of Stiffness of Single Implant Supported Crowns on the Resultant Stresses. A Finite Element Analysis. vol. 63, no. 1, pp. 172-184, 2016.

[44] Berge HX, Sorensen JA, Edelhoff D. Split energy factor theory in fracture analysis of dental ceramics. J Dent Res. vol. 80, pp.57-9, 2001.

[45] Geng J. P., Tan K. B. C., and Liu G. R., "Application of finite element analysis in implant dentistry: a review of the literature," *Journal of Prosthetic Dentistry*, vol. 85, no. 6, pp. 585–598, 2001.

[46] Soliman, T.A., R.A. Tamam, S.A. Yousief and M.I. El-Anwar. Assessment of stress distribution around implant fixture with three different crown materials. Tanta Dental Journal vol. 12, pp. 249-258, 2015.

[47] Bassit R, Lindstrom H, Rangert B. In vivo registration of force development with ceramic and acrylic resin occlusal materials on implant supported prostheses. Int J Oral Maxillofac Implants. vol. 17, pp. 17-23, 2002.

[48] Moreira W, Hermann C, Pereira JT, Balbinoti JA, Tiossi R. A three-dimensional finite element study on the stress distribution pattern of two prosthetic abutments for external hexagon implants. Eur J Dent. vol. 7, pp. 484-91, 2013.

[49] M. Sevimay, F. Turhan, M. A. Kiliçarslan, and G. Eskitascioglu, "-ree-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown," The Journal of Prosthetic Dentistry, vol. 93, no. 3, pp. 227–234, 2005.

[50] F. Vafaei, M. Khoshhal, S. Bayat-Movahed et al., "Comparative stress distribution of implant-retained mandibular ballsupported and bar-supported overlay dentures: a finite element analysis," Journal of Oral Implantology, vol. 37, no. 4, pp. 421–429, 2011.

[51] E. Romeo, D. Lops, E. Margutti, M. Ghisolfi, M. Chiapasco, and G. Vogel, "Implant-supported fixed cantilever prostheses in partially edentulous arches. A seven-year prospective study," Clinical Oral Implants Research, vol. 14, no. 3, pp. 303–311, 2003.

[52] de Kok, P., C.J. Kleverlaan, N. de Jager, R. Kuijs and A.J. Feilzer, Mechanical performance of implant-supported posterior crowns. J Prosthet Dent., vol. 114, pp. 59-66, 2015

[53] Güngör, M.B., and Handan Yilmaz, 2016. Evaluation of stress distributions occurring on zirconia and titanium implant-supported prostheses: A three-dimensional finite element analysis. J Prosthet Dent.; Vol. 116, pp. 346-355, 2016. Doi: 10.1016/j.prosdent.2016.01.022. PMid:27063944.