International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 10 (November 2014) www.ijirae.com

Factors Affecting on Stress Distribution of Angled Abutment Dental Implant-Bone Interface: A Computational & Experimental Review

Prof. Pankaj N. Dhatrak
Dept. of Mechanical Engineering
Maharashtra Institute of Technology
Pune 411038

Dr. Sumant S.
Dept. of Periodontics & Implantology
M. A. Rangoonwala College of Dental Science & Research Centre

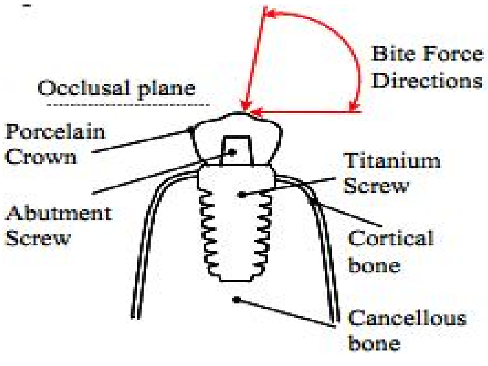
Pravin R. Lokhande
Dept. of Mechanical Engineering
Maharashtra Institute of Technology
Pune 411038

Abstract*— nowadays, angled abutment dental implants are being widely used for the dental prosthesis. The angled abutment introduced for implantation which is not possible with straight drilling of implants. Occlusal loads on dental implants causes stress generation at implant-bone interface which causes crestal bone loss and leads to loosening of implants failure. This review article provides an insight into various approaches used by the researchers for stress analysis of angled abutment dental implants. The objective of this paper is to provide guidelines for further work with aim increasing the success rate of the implantation. A literature search was conducted by using keywords such as stress analysis, angled abutment, and implant-bone interface. Among several articles and research papers, most of the articles related to dental prosthesis were shortlisted for complete reading and data extraction. Thus, the role of various parameters such as bone properties, surface characteristics of dental implant, implant design, abutment angulations, force factors and loading conditions is reviewed. Based on this review it is concluded that there are number of the factors which affects the results of stress analysis using computational and experimental methods. The effect of these parameters should be considered while planning for surgery and further research work. Moreover, there is need to apply any other simple experimental method for in vivo measurement is still desired.

***Keywords*— Stress Analysis, Dental Implant, Angled Abutment, FEA, Implant-bone interface.**

I. INTRODUCTION

Dental implants are the tapered, screw shaped threaded body which is drilled into the human jaw bone, and abutment is the interconnecting element in between implant & crown, used for the dental prosthesis. The dentist do the treatment as per the clinical procedure and selection of the implant, abutment is based on the dentist's experience and judgmental skills. The implants are required to be placed parallel to each other, parallel to the adjacent teeth and vertically aligned with axial forces. But in many clinical cases achieving this may be impossible due to deficiencies in alveolar bone. The angled abutment has been introduced to correct such cases [1]. The higher occlusal loads coming on the prosthetic element causes the high stress intensities at the implant bone interface. The stress generation at the implant-bone interface causes the crestal bone loss around the implant which leads to loosening type failure of the dental implant. In addition strong stresses are unbearable by patient and lead to very intense pains [2]. The fig bellow shows the bite force direction.



In this review we tried to collect the various studies on stress analysis of the angled abutment dental implant research to summarize the methodology, loading conditions, boundary conditions, analysis approach, assumptions made by researchers etc. This review will be helpful as guidelines and more correct way to perform research work.

II. IMPLANT-BONE INTERFACE

There is rapid interaction takes place at the implant-bone interface to hold the implant. The success rate of the implantation depend on many factors at the implant-bone interface. The osseointegration is one of the most important factors that decides the success of the implantation. It is initial requirement that for perfect osseointegration at this interface is the proper thread type of implant must be selected for which osseointegration obtained is 100%. The stability at the initial time of the implantation decides the rate of osseointegration [3] [4] Moreover the stress profile of the implanted angled abutment dental implant at implant-bone interface should be minimum and proper distribution of the stress is expected. Since improper stress distribution and higher stress intensities at implant-bone interface are unbearable by the patient and causes the intense pains to the patient. Now let us discuss the bone properties and implant surface characteristics in following points:

A. Bone Properties At Implant-Bone Interface

The mechanical properties of human bone are direction dependent i.e. bone is anisotropic and non-homogeneous. In some cases the cortical bone is assumed to be orthotropic. Many FEA assumes the homogeneous, isotropic & elastic properties for simplifications [5]. The bone shows the time dependent behaviour described as viscoelastic in certain conditions. The maximum value of the yield stress is found for compression along the main axis of a long bone is 180 MPa and that for tensile is 120 MPa. The yielding under tensional loading in plane normal to main axis of bone is 55 MPa. Bone density ensures the osseointegartion. Higher the value of bone density more chances of the faster osseointegrations.

Reilly et al and Burstein have been reported bone to be transversely isotropic [6] [7]. Kneits, Malmeister and Ashman described bone as orthotropic (i.e. $E_1 = E_2 = E_3$) [8] [9]. The mandible has been reported as transversely isotropic, with the stiffest direction oriented the arch of mandible [10]. Cancellous bone in human mandible exhibited transverse isotropy by compression test. Elastic modulus of bone was greatest in mesio-distal direction (907 MPa), lowest in infero-superior direction (114 MPa) and intermediate in bucclo-lingual directions (511 MPa) [11]

B. Surface Characteristics of Dental Implant

The implant surface conditions influences the process of osseointegartion, bone loss & stability of the implants [12] The square threaded implant have higher bone implant contact (BIC) and higher reverse torque value. Removal torque values higher for roughened surface [13]. The square thread implant has higher BIC value (74.37 percent) compared with V-shape (65.46 percent) and reverse buttress (63.05 percent). The immediately loaded implants, despite surface condition, presented higher BIC value average 80.06 percent [14]. No significant changes concerning bone loss were detected around implant with rough surface placed at crest, however, implant with smooth collars of 1.5mm below the crest resulted in bone loss [15]. Both fine and rough threaded implant system showed similar behavior with straight abutment and micro motion. On the other hand, when angled abutments are used fine threaded system showed less displacement and rotations than rough threaded one [16]. The rough threaded implants are more stable than the fine threaded since osseointegration is more. The commonly used surface treatments are acid etching (osseotite), plasma spraying, sand blasting, anodizing, laser treatment etc. With acid etching 78-85 % BIC value can be obtained [17]. With acid etched and turned surface 72.35 % BIC value is obtained [18]. For sand blasted and acid etched 76.6 % BIC value is obtained.

III. Geometry of Dental Implant

The angled abutment dental implant consist of the two main parts that is implant (fixture) and angled abutment. Implants are available in four basic thread types that are v, square, buttress and reverse buttress thread profiles. Let us discuss the geometry of angled abutment dental implant with following points.

A. Implant Design

The microscopic consideration of the implant design is significant during the initial placement of implant and also at time of loading. While the macroscopic one is playing vital role during early loading as well as mature loading period. The cylindrical implant offers the ease in surgical implantation however interface is significantly larger shear loaded. On the other hand smooth sided, tapered and cylindrical implants offers compressive load component to be delivered to bone around the implant at implant-bone interface [19]. The higher the taper for implant, higher magnitude of the compressive load component delivered to bone at implant-bone interface. The smooth body causes the shear load at implant-bone interface. While talking with respect to load carrying capacity, of the implant when implants are compared to screw jacks with vertical loads only, implants with larger core diameter have a greater load carrying capacity. The threads of the implants are designed to maximize the contact area, to enhance the transfer of stresses to interface and fascinates the dissipation of occlusal loads at bone implant interface [20]. Functional surface area per unit length of implant can be modified by altering three geometric thread parameters: Pitch, thread shape, thread depth [21]. Talking with respect to thread pitch, greater the pitch, greater is the surface area and lesser will be stresses [22]. The greater the thread depth, greater will be surface area and lesser will be stresses if all other parameters hold equal. The implant body taper may lead to higher stresses especially in shorter implant length [23].

B. Abutment Angulations

The angle of the abutment used for prosthetic elements is one of the important factor that will affect stress distribution at implant bone interface. The study shows that the use of the angled abutment could result in decreased stress on surrounding bone of implant when implant are not placed in ideal axial position [24]. The abutment angulations up to 25^0

can increase the stress in peri-implant bone by 18 % [25]. Implant and cortical bone strain were higher for an angled abutment of 20 % than that for straight abutment [26]. The one study stated that angled abutment may decreases strain on bone when restoring the implant in anterior maxilla but not specified the angle to be taken for surgery [27]. The stress profile of 1^0 tilted implant placement angle was found to be optimum for applied static load [24]. Also the maximum stress induced by masticatory force incident on prosthetic element can be significantly reduced by implant placement angle.

IV. FORCE FACTORS

In the force factors we will discuss the type of forces acting on the angled abutment dental implants and effect of occlusal overloading.

A. TYPE OF FORCES ON DENTAL IMPLANTS

There are three type of forces acts on the dental implants during the mastication of food: Tensile, compressive and shear. Bone is strongest for compressive forces and 30 % weaker when subjected to tensile forces and 65 % weaker when loaded in shear [28]. For this reason one should try to limit shear loads since it is least resistant to fracture under these loading conditions. Doing this is important in region of less bone density, because bone strength is directly proportional to its density [29]. An increased width of implant may decrease offset load and increase the amount of implant-bone interface subjected to compressive load.

B. EFFECTS OF OVERLOADING

Abutment screw loosening detected in an overall average of 6% of dental implantation [30]. While the crown with single tooth showed highest rate of 25 % in earlier stage of screw design. The very recent research work indicated that this has been reduced to 8 % average, with multiple unit fixed prosthesis at 5% average and implant over dentures at 3%. The larger amount of stress applied to prosthesis the greater is the risk of screw loosening. Cantilevers are also gives rise to screw loosening as it increases forces in directly proportional relationship with length of cantilevers [31]. The larger crown height connected to the abutment the greater the force coming on screw and the greater is risk of screw loosening. The height or depth of anti-rotational component of the implant body also possible to affect amount of force applied to abutment screw. The deeper the hex height less stresses will be applied to screw and corresponding lower risk for abutment screw loosening [32]. Larger diameter implant with larger platform dimensions reduces force applied to an abutment screw. The screw loosening may be reduced with a preload force.

C. LOADING CONDITIONS

All the FEA study assumes static loading conditions. The effect of the loading magnitude and direction ensures the stress distribution at the implant bone interface [33]. The force of 100 N is considered acting vertically stress analysis of angled abutment implant is done by ignoring the transverse component [34]. Another study considered static load of 150 N along implant and abutment axis [35]. In one of the study static load of 17.1 N, 114.6 N & 23.1 N in lingual, axial & mesio-distal directions respectively but this is very difficult to verify practically [24]. Both implant and abutment axis loading is found to be important for the stress analysis of the implant-bone interface.

V. EXPERIMENTAL STUDIES

The outcome of the research cannot be implemented successfully if it lacks the experimental validations. The experimental studies for clinical cases can be in vitro or in vivo. In vitro study is comparatively simpler than the in vivo and requires the results to be correlated with the actual physical conditions. However in vivo provides the clinical expectations but study is very difficult because of lack of the measurement systems. In vitro study can be done by finding a most influencing parameter on success rate of implantation. These parameters can be varied accordingly to achieve best performance by applying mechanical principles. E.g. stress intensities around the implant bone interface causes the bone damage around the implant and higher intense pains. So stress distribution can be most influencing parameter to be a key factor for success rate of implantations. One will prefer to use the implant which will have minimum stress profile.

Certain in vitro experimental studies include Photo elastic Stress Analysis, Strain Gauge Measurement, Digital Image Correlation (DIC), Stress Frozen Technique (3 D Photo elasticity), X-ray Diffraction technique etc. The photo elasticity is the unique method that provides the opportunity for determination of stresses inside the body.

A. PHOTO ELASTIC STRESS ANALYSIS

The outcome of the research cannot be implemented successfully if it lacks the experimental validations. The experimental studies for clinical cases can be in vitro or in vivo. In vitro study is comparatively simpler than the in vivo and requires the results to be correlated with the actual physical conditions. However in vivo provides the clinical expectations but study is very difficult because of lack of the measurement systems. In vitro study can be done by finding a most influencing parameter on success rate of implantation. These parameters can be varied accordingly to achieve best performance by applying mechanical principles. E.g. stress intensities around the implant bone interface causes the bone damage around the implant and higher intense pains. So stress distribution can be most influencing parameter to be a key factor for success rate of implantations. One will prefer to use the implant which will have minimum stress profile. Certain in vitro experimental studies include Photo elastic Stress Analysis, Strain Gauge Measurement, Digital Image Correlation (DIC), Stress Frozen Technique (3 D Photo elasticity), X-ray Diffraction technique etc. The photo elasticity is the unique method that provides the opportunity for determination of stresses inside the body.

VI. Computational Studies

Author	Aim	Analysis Approach	Conclusion	Future Scope
R Harirforough [39] (2014)	To study the effect of implant angulation on resonance frequency a dental implant	CT based finite element modal analysis	-The parameters rotations and contact area at implant-bone interface indicated least contributors the RF and orientation of implant	-
I. Thiruselvam [24] (2013)	Study the stress distribution in patient's mandible, implant & abutment by varying implantation angle by 0°, 1° and 2° tilt.	-FEA & simulation for one natural mastication cycle is done	-Max stress observed in cervical region of implant -stress profile 1° tilted implant placement angle is found optimum -The stresses induced on prosthetic element can be minimized by altering the implantation angle	After 15-20 years of implant function performance of this prosthesis could be evaluated & compared to any other prosthesis
Juraj Borozovi [40] (2013)	To obtain the force related interferometry pattern of the loaded implant by varying the diameter and changing the brands	Digital Holographic Interferometry Analysis	The interferometry data of 10 implant and abutment assemblies shows that there are lot of the benefits with use of the wider diameter implants	The implant abutment assemblies should be studied with oblique forces
Kebin Tian [5] (2012)	Study effect of the use of angled abutment on stresses of surrounding bone of single unit dental implant	-3D FEA & Simulation at ideal axial position or at angled position	-Angled abutment results in decreased stress when placed at angulated positions -Under certain loading conditions angled abutment result in decreased stress and offers better stress distribution at implant bone interface	-To analyze principal stress & strain -Influence of implant bone interface under various conditions
Calcida Cunha [41] (2012)	To study the stress distribution at implant-bone interface by simulation of the platform switching and using micro threads on angled abutment	3D FEA	-Platform switching helps to reduce stress-strain concentration at cortical bone. The stresses increases for the trabecular bone using platform switching -The stress concentrations are higher by using micro threads for cortical bone, but this is not case with trabecular bone, when compared with smooth implants	Needs more research to be conducted on implants with micro threads and platform switching, also needs more clarification on effect of micro threads on implant stability

I Hasan [16] (2011)	Study the effect of rough verses fine threaded cervical region of dental implant with immediate loading for both straight and 20° angled abutment on primary stability	2D FEA	-Both fine & rough implant system showed same displacement & rotation with straight abutments -Numerically, stresses within 35-45 MPa in cortical bone for both system	For better stability fine cervical threads should be used with the angled abutment
Pattapon Asvanun [38] (2011)	To study the load transfer characteristics of implant with internal and external abutment connection by applying loads at 3 positions	2D Photo elastic stress analysis	-When loads were applied on model the direct stress distribution at implant-abutment seen and stress generated was more for external implant abutment connection than internal when models were loaded unilaterally and anteriorly	Further investigation can be done to study the stress transfer for angled abutment dental implants
Ting Wu [42] (2010)	Study biomechanical performance and comparison of custom and conventional angled abutment using non-linear FEA	-3D Non-linear FEA -contact analysis is done -simulation is done	-No distinct difference in between stress distribution & magnitude at implant bone interface using custom & angled abutments -Higher stress of cortical bone are located at crestal region around the implant for compression of the prosthetic element.	Need to carry the laboratory tests & clinic experiments to improve & practice system
N. Djebbar [2] (2009)	Study effect of load direction on stress distribution in dental implant	-3D Finite Element Analysis	-A key factor for success of implant is the way in which stresses are transferred to bone	Analysis of implant-bone interface under choc loading
G Duboisis [43] (2006)	Study the biomechanical behavior of the upper lateral incisor for angled abutment implant	Software used -Hypermesh7 & MSC-Marc software	-Safe load is 44 N after surgery to approximately 160 N after 26 months -Use of abutment generated bending stress inside bone & implant -The abutment can be safely used for incisor at upper lateral location for external load range of 0-200 N	Concept of safe load could be applied for oral rehabilitation treatment planning
Jie Yang [44] (2006)	Study the mechanical behavior of FGDM implant and surrounding bone with static and harmonic forces	3D FEA	-The FGDM implants can be used to reduce the stress intensities around implant-bone interface -Good quality of osseo integration reduces value of the maximum stress	-
Dincer Bozkoya [45] (2004)	-To study mechanics of the tapered integrated screwed implant with abutment	-	-The tightening torque values are larger than the loosening torque -The loosening torques and tightening torques are highly affected by coefficient of friction at implant-bone interface	To solve the complexity with the coefficient of friction and many factors affecting on it more research work is needed

VII. CONCLUSION

The role of various parameters such as bone properties, surface characteristics of dental implant, implant design, abutment angulations, force factors and loading conditions is reviewed. Based on this review it is concluded that there are number of the factors which affects the stress distribution at implant-bone interface using computational and experimental methods. The effect of these parameters should be considered while planning for implantation and further research work. Moreover, there is need to apply any other simple experimental method for in vivo measurement is still desired.

VIII. FUTURE SCOPE

The future work proposed includes the stress analysis of the angled abutment dental implant and verification using the finite element analysis (FEA). The experimental method like Photo elasticity will be used to study the stress distribution at angled abutment implant-bone interface. The simulation will be done prior implantation surgery for one natural mastication load (static) by varying abutment angle. This work will provide best abutment angle and thread profile.

REFERENCES

[1] Sethi A, Kaus T and Sochor P, "The use of angulated abutment in implant dentistry: five-year clinical result of an ongoing prospective study", Int J Oral Maxillofac Implants, Vol.15, pp. 801-810, Nov. 2000.
[2] N. Djebbar, B. Serier, B. Bachir Bouiajra and S. Benbarek, "Analysis of effect of load direction on the stress distribution in dental implant", Materials and Design, Vol.31, pp. 2097-2101, Oct. 2009.
[3] Brunski JB and Moccia AF Jr Pollack, "The influence of functional use of endosseous dental implant on tissue implant interface II", J Res Dent, Vol.58, pp. 1970-1980, 1979.
[4] Soballe K, Hanseen ES and B-Rasmussen, "Tissue ingrowth into titanium and hydroxyapatite-coated implants during stable and unstable mechanical condition", J Orthop, Vol.10, pp. 285-299, Oct. 1994.
[5] Kebin Tian, " Angled abutment result in increased or decreased stress on surrounding bone of single unit dental implants: A finite element analysis ", Medical Engineering & Physics, Vol.23, pp. 1526-1531, Oct. 2012.
[6] Reilly DT and Burstein AH, "The elastic and ultimate properties of compact bone tissue", J Biomech, Vol.8, pp. 393-400, Oct. 1995.
[7] Yoon HS and Kot Z JL, "Ultrasonic wave propagation in human cortical bone II: measurement of elastic properties and mocroharndness", J Biomech, Vol.9, pp. 459, 1976.
[8] Knets I, and Malmeister A, "Deformability and strength of human contact bone tissue, In Bankov G", Mechanics of Biological Solids, 1977.
[9] Ashman RB, Crowin SC and Van Buskirk WC, "A continues wave technique for measurement of the elastic properties of bone", J Biomech, Vol.17, pp. 349-361.
[10] Ashman RB, Crowin SC and Van Buskirk WC, "A continues wave technique for measurement of the elastic properties of bone ", J Biomech, Vol. 17, pp. 349-361, Oct. 1984.
[11] Toneti MS and Schmid J, "Pathogenesis of implant failure", Vol. 4, pp. 127-138, 2000.
[12] Steigenga J, Al-Shammari K and Misch C, "Effect of implant thread geometry on percentage of osseointegrartion and resistance to reverse torque in the tibia of rabbits", Vol.75, pp. 1233-1241, Oct. 2004.
[13] Degidi M, Scarano A, and Lezzi G, "Periimplant bone in immediately loaded titanium impalnt: histologic and histomorphometric evaluation in human: a report of two cases", Clin Implant Dent Res, ,Vol.5, pp. 170-175, Oct. 2003.
[14] Shalabi MM, Wolke JG and Jansen JA, "The effect of implant surface roughness and surgical technique on implant fixation in an in vitro model", Clin Oral Implants Res, Vol. 17, pp. 172-178, 2006.
[15] Hermann JS, Coachran DL, Nummikoski PV, "Crestal bone changes around titanium impl;ants: a radiographic evaluation of unloaded and non-submerged and submerged implants in canine mandible", J Periodontal, Vol.68, pp. 1117-1130, Nov. 1997.
[16] I Hasan, B. Roger, F, Heinemann and L. Keiling, "Influence of abutmant design on the success of immediately loaded dental implants: Experimental and numerical studies", Mechanical Engineering & Physiscs, Vol.34, pp. 817-825, Sept. 2011.
[17] Testori T, Szmukler-Moncler S and Francetti L, "Immediate loading of oeeotite implants: a case report and histologic analysis after 4 month of occlusal loading", Int J Periodontic Restorative Dent, Vol. 21, pp. 451-459, 2001.
[18] Trisi P, Lazzara R and Rao W, "Bone implant contact and bone quality: evaluation of expected and actual bone contact on machined and osseotite implant surfaces", Int J Periodontic Restorative Dent, Vol. 22, pp. 535-545, 2002.
[19] Lemons J, "Biomaterials in implant dentistry", Contemporary Implant Dentistry, 1993.
[20] Strong JT, Misch CE and Bidez MW, "Functional surface area: thread form parameter optimization for implant body design", Comprend Contin Educ Dent, Vol.19, pp. 4-9, 1998
[21] Misch CE and Bidez MW, "A scientific rationale for dental implant design", Contemporary Implant Dentistry, 1999.

[22] Riegen MR, Maybery M and Brose Mo, "Finite element analysis six endosseous implants", J Prosthet Dent, Vol.63, pp. 671-676, 1990.
[23] Jeffcoat MK and Reddy MS, "A comparison of hydroxyapatite (HA)- coated threaded, HA-coated cylindric and titanium threaded endosseous dental implant", Int J Oral Maxillofac Implants, Vol. 18, pp. 406-410, 2003.
[24] Iniyan Thiruselvam N, Dhananjay M Kulkarni and Savio D.S.A Lourenco, "Properative simulation of implant angulation effect on mandibular masticatory stresses- a finite element study", Procedia Engineering, Vol.64, pp. 8145-824, 2013.
[25] Kao HC, Gung YW, and Chung TF, "The influence of the abutment angulation on micromotion level for immediately loaded implants: 3D finite element analysis'", Int J Oral MaxillofacImplants, Vol.23, pp. 623-630, 2008.
[26] Lin CL, Wang JC, Ramp LC, and Lilu PR, "Biomechanical response of implant system placed in maxillary posterior region under various condition of angulation bone density and loading", Int J Oral Maxillofac Implants, Vol.34, pp. 817-815, Dec. 2012.
[27] Saab XE, Griggs JA, Powers JA and Powers JM, "Effect of abutment angulation on the strain of the bone around an implant in anterior maxilla: a finite element study", J Prosthet Dent, Vol.97, 85-92, 2012.
[28] Crowin SC, 'Bone Mechanics', 1989.
[29] Misch CE, Qu Z, and Bidez MW, "Mechanical properties of trabecular bone in the human mandible implications for dental treatment planning and surgical placement", J Oral Maxillofac Surg, Vol.57, pp. 700-706, 1999.
[30] Goodacre NH, Bernal G and Rungcharassaeng K, "Clinical complications with implants and implant prosthesis", J Prosthet Dent, Vol.90, pp. 121-132, 2009.
[31] Kallus T and Bessing C, "Loose gold screw frequently occur in full arc fixed prosthesis supported by osseointegrated implants after 5 years", Int Journal Oral Maxillofac Implants, Vol.9, pp. 169-78, 191.
[32] Boggan S, Strong JT and Misch CE, "Influence of hex geometry and prosthetic table width on static and fatigue strength of dental implants", J Prosthet Dent, Vol.82, pp. 436-490, 1999.
[33] Kebin Tian, 'Angled abutment result in increased or decreased stress on surrounding bone of single unit dental implants: A finite element analysis', Medical Engineering & Physics, 2012, Vol.23, 1526-1531.
[34] Kong Liang, Zhao Yunzhuan, Hu Kaijin, Li Dehua and Wu Zian, "Selection of the implant thread pitch for optimal biomechanical properties: a three dimensional finite element analysis", Adv Eng Softw, Vol. 40, pp. 474-480, 2009.
[35] I Hasan, B. Roger, F, Heinemann and L. Keiling, "Influence of abutmant design on the success of immediately loaded dental implants: Experimental and numerical studies", Mechanical Engineering & Physiscs, Vol.34, pp. 817-825, Sept. 2011.
[36] S. Chereli, "Tilted orthodontic micro implants: a photoelastic stress analysis', European Journal of Orthodontics", Vol. 5 pp. 1-5, 2011.
[37] Ueda C, Markarian RA, Sendyk CL, and Lagana DC, "Photoelastic analysis of stress distribution on paralleel and angled implants after installation of fixed prosthesis", Braz Oral Res, Vol.18(1), pp. 45-52, 2004.
[38] Pattapon Asvanund, DDS MSD and Steven M. Morgano, "Phtoelstic stresses analysis of external versus internal implant-abutment", J Prosthet Dent, Vol.106, pp. 266-271, 2011.
[39] R Harirforoush, S. Arzanpour and B. Chehroudi, "The effect of implant angulation on resonance frequency of dental implant", Medical Engineering & Physics, Vol. 36, pp. 1024-1032, May 2014.
[40] Juraj Brozovic, Nazif Demoli, Nina Farkas and Mato Susic, "Properties of axially loaded implant-abutment assemblies using digital holographic interferometry analysis", Dental Materials, Vol. 30, pp. e17-e27, Dec. 2013.
[41] Calcida Cunha Ferraz DDS, "Influence of mocrothreads and platform switching on stress distribution in bone using angled abutment", Journal of Prosthoontic, Vol. 56, pp. 256-263, Feb. 2012.
[42] Ting Wu, Wenhe Liao, Ning Dai and Chumbo Tang, "Design of a custom angled abutment for dental implants using computer-aided design and non-linear finite element analysis", Journal of Biomechanics, Vol. 43, pp. 1941-1946, Mar. 2010.
[43] G. Dubois, M. Dass, A.S. Bonnet and P. Lipinski, "Biomechanical study of a prosthetic solution based on an angled abutment: Case of upper lateral incisor", Medical engineering & Physics, Vol. 29, pp. 989-998, Oct. 2006.
[44] Jie Yang and Hong-Jun Xiang, "A three-dimensional finite element study on biomechanical behavior of an FGDM dental implant in surrounding bone", Joournal of Biomechanics, Vol. 40, pp. 2377-2385, Nov. 2006.
[45] Dincer Bozkaya and Sinan Muftu, "Mechanics of tapered interference fit in dental implants", Journal of Biomechanics, Vol. 36, pp. 1649-1658.

