

Comparative effect of implant-abutment connections, abutment angulations, and screw lengths on preloaded abutment screw using three-dimensional finite element analysis: An *in vitro* study

Krishna Chaitanya Kanneganti, Dileep Nag Vinnakota, Srinivas Rao Pottem, Mahesh Pulagam

Department of Prosthodontics, Narayana Dental College and Hospital, Nellore, Andhra Pradesh, India

Abstract

Purpose: The purpose of this study is to compare the effect of implant-abutment connections, abutment angulations, and screw lengths on screw loosening (SL) of preloaded abutment using three dimensional (3D) finite element analysis.

Materials and Methods: 3D models of implants (conical connection with hex/trilobed connections), abutments (straight/angulated), abutment screws (short/long), and crown and bone were designed using software Parametric Technology Corporation Creo and assembled to form 8 simulations. After discretization, the contact stresses developed for 150 N vertical and 100 N oblique load applications were analyzed, using ABAQUS. By assessing damage initiation and shortest fatigue load on screw threads, the SL for 2.5, 5, and 10 lakh cyclic loads were estimated, using fe-safe program. The obtained values were compared for influence of connection design, abutment angulation, and screw length.

Results: In straight abutment models, conical connection showed more damage (14.3%–72.3%) when compared to trilobe (10.1%–65.73%) at 2.5, 5, and 10 lakh cycles for both vertical and oblique loads, whereas in angulated abutments, trilobe (16.1%–76.9%) demonstrated more damage compared to conical (13.5%–70%). Irrespective of the connection type and abutment angulation, short screws showed more percentage of damage compared to long screws.

Conclusions: The present study suggests selecting appropriate implant-abutment connection based on the abutment angulation, as well as preferring long screws with more number of threads for effective preload retention by the screws.

Keywords: Dental, implant, preload, screw

Address for correspondence: Prof. Dileep Nag Vinnakota, Department of Prosthodontic Dentistry, Narayana Dental College and Hospital, Nellore, Andhra Pradesh, India.

E-mail: dileepnagmids@yahoo.co.in

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INTRODUCTION

Dental implants underwent numerous alterations and advancements in the design.^[1] Despite this, failures at implant or prosthesis level are common; of the implant ones, loss of integration, soft tissue defects, positional failures, and biomechanical failures are reported to be the major categories.^[1,2] Among the biomechanical complications, screw loosening (SL) is most commonly encountered.^[3-8]

SL and decrease in joint preload below a critical level contributes to the joint instability and microgap formation,^[9] which can lead to fracture of the overlying prostheses and implant body. Even the micromovements produced due to SL initiate a pumping effect for the ingress of microorganisms which destruct the surrounding bone.^[10] Therefore, SL is an exemplary of inadequate biomechanical design and/or occlusal overloading that affects the longevity of the implants;^[11] hence, the concerted effort by the researches is to assess and reduce this problem. For assessing the SL, both *in vitro* and *in vivo* studies can be employed. However, as *in vivo* studies, are time consuming and difficult, certain *in vitro* mechanical studies have been conducted to evaluate screw joint stability of various connections, maintenance of preload and dimensions of the abutment screw after loading, lateral oblique cyclic loading on abutment SL, torque stability of different abutment screws, torque removal evaluation of screws after tightening and loosening cycles, and influence of abutment angulation on SL.^[12-15] Concurrently, the finite element analysis, an effective tool for simulating oral conditions and predicting the behavior of dental restorations has been introduced into dentistry. This procedure was considered by some authors in determining the loss of preload in abutment screw, factors affecting preload and influence of implant/abutment joint design on SL.^[16-19]

Based on the observations from the existing studies, to reduce the possibility of SL, techniques such as centering the occlusal contacts, flattening the cuspal inclination, applying the correct torque when tightening the abutment screw, narrowing the buccolingual width of the crown, and reducing the cantilever length have been recommended.^[13,20-23] However, there are certain drawbacks in this field which demand further studies. The literature on internal antirotation configuration is sparse, even though proved to be superior over external ones.^[24] An additional contributing lacuna is the lack of studies that compared the conical connection with hex and tri-lobed connection, under dynamic loading conditions. All these necessitate a systematic approach, one such being

nonlinear dynamic analysis that is commonly employed in industrial fields, to simulate and predict the dynamic behavior of implants with these connections. Hence, the present study was done to determine the effect of dynamic cyclic loading on preloaded abutment screw and the influence of connection designs, abutment angulations, and screw lengths on SL using 3D finite element analysis. The null hypothesis stated was that the connection design, abutment angulation, and screw length have no influence on the SL of dental implant.

MATERIALS AND METHODS

Geometrical designing of three-dimensional models using software Parametric Technology Corporation Creo (Needham, Massachusetts, United States) [Figures 1 and 2]

Implant models

3D models of implants with two different connections, conical connection with hex (NobelBiocare Replace RP) and tri-lobed connection (NobelBiocare Replace tapered RP), both with dimensions of 5.0 mm diameter and 13 mm length, were designed.

Abutment models

Two models of implant abutments each (Regular platform implants), conical connection with hex and tri-lobed connection, of 5 mm diameter, were designed in two different angulations; one straight (0°) and another angulated (25°).

Abutment screw models

One short-screw model with five threads (0.44 mm pitch) and another long screw with nine threads (0.367 mm pitch) were designed.

Crown model

A crown model resembling mandibular first molar with 8 mm length and 6 mm diameter was designed.

Bone model

Computed tomography scan of human mandible with D2 density bone (a thick layer of 2 mm of compact bone

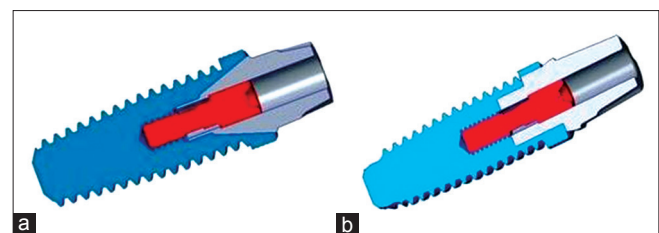


Figure 1: (a) Conical connection with hex (straight abutment-short screw); (b) trilobe connection (straight abutment-long screw)

surrounding a core of dense trabecular bone) was taken and section in the region of mandibular first molar used to develop the model.

The material properties incorporated in the study are represented in Table 1.^[25]

All these models were assembled to form a total of eight simulations; in each implant-connection type (conical connection with hex and tri-lobed connection) four different assemblies were designed: Straight abutment and short screw (5 threads); straight abutment and long screw (9 threads); angulated abutment (25°) and short screw (5 threads); angulated abutment (25°) and long screw (9 threads). The abutment body along with screw was tightened with a torque of 25N cm, and the friction coefficient between internal threads of implant and abutment screw was assumed to be 0.25.

Discretization process [Figure 3]

This procedure included creating the mesh, elements with their respective nodes, and defining boundary conditions. An axisymmetric model of an implant was created by the application of CAXA elements; the assumed material characteristics of the jaw bones being linear, homogeneous and isotropic. This 8-node biquadratic axisymmetric quadrilateral element was selected as it provides for the modeling of bodies of revolution under axially symmetric loading conditions. Convergence study, which determines the minimal size of the mesh required to eliminate its influence on stress, was employed to validate the finite element model. The total number of elements and nodes for each model are represented in Table 2. The boundary conditions of implants were modeled as a portion of the jaw bone. The geometry of a small part of jaw surrounding

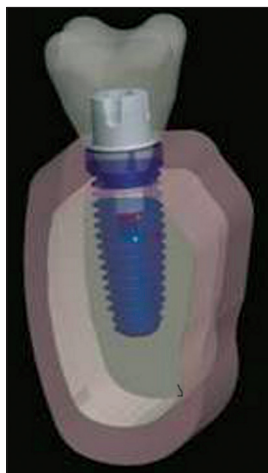


Figure 2: Casting-assistant device assembly (trilobe connection-straight abutment-short screw)

the implant was simplified, which enabled consideration of the changes in implant fixing conditions. The material model of bone was simplified to a linear elastic description; both anterior and posterior bone boundary regions were constrained and the support at the bottom omitted which permitted bending of the model. The realistic clinical situation was represented in these aspects.

Finite element analysis [Figure 4]

Further analysis was carried out by ABAQUS/standard finite element program (Inc. Version 6.14) and fe-safe program Safe Technology Ltd, Sheffield Version 6.5 (Willis House, Peel Street, Sheffield, United Kingdom).

Force of magnitude, 150N vertically (perpendicular to the occlusal surface), and 100N obliquely (at angle of 45° to the occlusal surface)^[26] were applied separately on the cusps of tooth. After load application, a nonlinear contact stress analysis was performed on the assemblies by applying contacts between different parts in ABAQUS/Standard. Then, the output database file was exported to fe-safe,

Table 1: Material properties incorporated during geometrical designing of three dimensional models

Material	Young's modulus (GPa)	Density (kg/m ³)	Poisson's ratio	Yield strength (MPa)	Tensile strength (MPa)
Cortical bone	13.7	-	0.3	-	-
Cancellous bone	1.37	-	0.3	-	-
Titanium implant	110	-	0.19	615.2	742.4
Abutment	110	4500	0.19	802.8	970.4
Abutment screw	110	4500	0.19	832.3	1004
Zirconia (crown)	210	-	0.3	-	-
Cement	8.3	-	0.35	-	-

Table 2: Elements and nodes during discretization

Model	Element type	Elements	Nodes
Cancellous bone	CAX8R	2479	7780
Cortical bone	CAX8R	929	3052
Implant	CAX8R	1059	3552
Abutment	CAX8R	615	2008
Abutment screw	CAX8R	1059	3398
Crown	CAX8R	411	1358
Total		6552	21,148

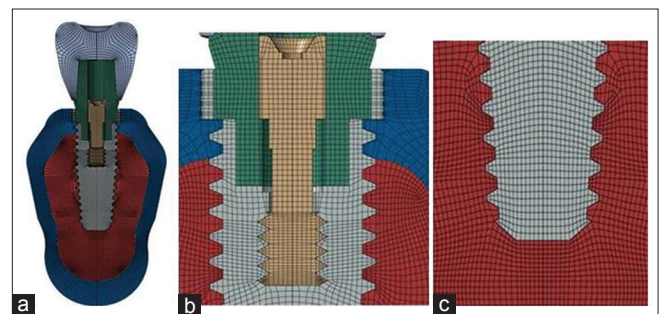


Figure 3: (a) Meshed model; (b) meshed model-upper part magnified; (c) meshed model-lower part magnified

in which all the stresses and strains were imported to perform fatigue analysis, using high- and low-cyclic fatigue method. The calculations of fatigue life were based on the relationship between amplitude of engineering stresses and the number of cycles to failure. The fatigue calculations required the extrapolation of the stresses obtained from integration points to the nodes of finite elements for which shape functions were used (ABAQUS Manuals). The stable material cyclic response was approximated with the help of the cyclic stress-strain curve. To measure the resistance to SL, frictional dissipation energy accumulated over a whole process between the contact surfaces was chosen, which was calculated based on velocity field, frictional traction, and boundary (contact surfaces). As a cyclic fatigue load, dynamic loading (in sinusoidal pattern) was repeated for 2.5 lakh times using fe-safe fatigue analysis software. In a similar manner, the load was repeated for 5 and 10 lakh cycles separately and the models were analyzed; SL was

estimated using damage initiation and shortest fatigue life on the abutment screw threads and internal threads of the implant.

RESULTS

The maximum stress concentrations for vertical load of 150N and oblique load of 100N at an angle 45° are represented in Table 3. The stress on bone, implant, abutment, and abutment screw was not in a regular pattern; connection type, abutment angulation, or screw length could not particularly influence the stress concentration. The strain, deflection, and percentage of abutment screw damage for vertical and oblique loads at 2.5, 5 and 10 lakh cycles are presented in Table 4. In straight abutment models, conical connection showed greater percentage of damage (18.4%–72.3% for short and 14.3%–56.1% for long) when compared to trilobe (16.45%–65.73% for short and 10.1%–40.3% for long) at all the cycles, whereas in angulated abutments, trilobe (19.2%–76.9% for short and 16.1%–64.2% for long) demonstrated more compared to conical (17.7%–70% for short and 13.5%–53.1% for long). The short screws showed more percentage of damage compared to long screws, in both conical connection with hex and trilobed connections, irrespective of the abutment angulation.

DISCUSSION

Implants have been successfully used as a viable treatment modality for the prosthetic rehabilitation of partial and complete edentulism. Among the complications reported, SL is well known and severe,^[20] as this necessitates removal of overlying restoration to gain access to the screw which might damage the implant restoration. SL has been the most frequently experienced problem during the first year, in a group of 107 implants as reported by Henry *et al.*, and in a 3 year prospective study by Jemt and Pettersson; this complication was

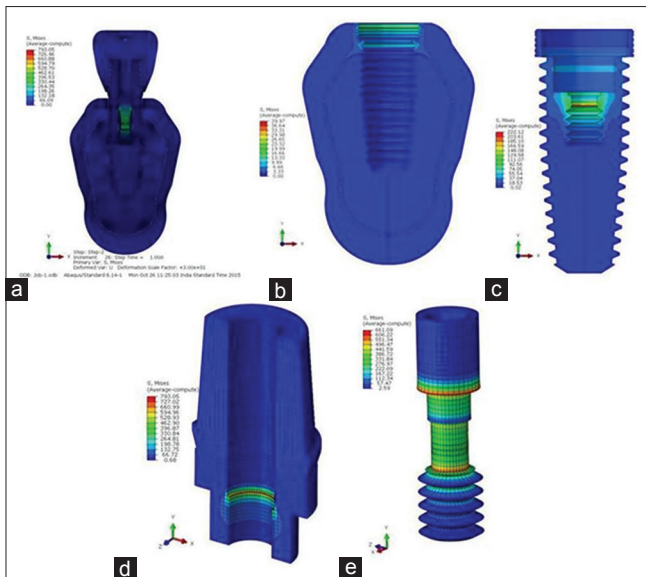


Figure 4: (a) Von Mises stresses-assembly; (b) Von Mises stresses-bone; (c) Von Mises stresses-implant; (d) Von Mises stresses-abutment; (e) Von Mises stresses-abutment screw

Table 3: Maximum stress concentrations for vertical load of 150 N and oblique load of 100 N at an angle 45°

Model (stress in MPa)	Conical connection with hex versus trilobe connection							
	Straight short		Straight long		Angulated short		Angulated long	
	Conical	Trilobe	Conical	Trilobe	Conical	Trilobe	Conical	Trilobe
Vertical load of 150 N								
Bone	20	39.97	21	12.97	21.5	21.4	21.3	24.2
Implant	351.83	222	433.4	468.07	460.7	162.2	404.9	219.7
Abutment	713.57	793	744.5	687.43	742.5	845.3	748.7	838.2
Abutment screw	743.62	661	575.4	618.58	710.4	776	566.6	777.6
Oblique load of 100 N at an angle 45°								
Bone	10.4	24	12	6.8	12.2	12.5	12.3	12.5
Implant	351.9	222.1	435.7	466.9	462.9	162.6	406.5	219.9
Abutment	716.1	796	749.8	688.9	749.1	852.6	755	837.3
Abutment screw	746.4	665	581.3	620.1	718.2	781.2	572.4	777.6

Table 4: Strain, deflection, and percentage of abutment screw damage

Parameters	Conical connection with hex versus trilobe connection							
	Straight short		Straight long		Angulated short		Angulated long	
	Conical	Trilobe	Conical	Trilobe	Conical	Trilobe	Conical	Trilobe
For vertical load of 150 N								
Strain	0.00687	0.0072	0.00807	0.00717	0.01019	0.00726	0.00664	0.00714
Deflection (mm)	0.00733	0.0113	0.01163	0.0117	0.01179	0.00534	0.01171	0.00552
Damage (2.5 lakh cycles) (%)	18.40	16.45	14.30	10.10	17.70	19.20	13.50	16.10
Damage (5 lakh cycles) (%)	36.50	32.65	28.20	20.20	35.20	38.50	26.70	32.10
Damage (10 lakh cycles) (%)	72.30	65.73	56.10	40.30	70	76.90	53.10	64.20
For oblique load of 100 N at an angle 45°								
Strain	0.00691	0.0072	0.0007	0.00718	0.0103	0.00719	0.00671	0.00714
Deflection (mm)	0.0067	0.01083	0.01102	0.01096	0.01118	0.00571	0.0111	0.00497
Damage (2.5 lakh cycles) (%)	18.40	16.45	14.30	10.10	17.70	19.20	13.50	16.10
Damage (5 lakh cycles) (%)	36.50	32.65	28.20	20.20	35.20	38.50	26.70	32.10
Damage (10 lakh cycles) (%)	72.30	65.73	56.10	40.30	70	76.90	53.10	64.20

observed in 49% and 20.8% of maxillary and mandibular implant-supported prostheses.^[4,5] This was especially with single-tooth restorations in premolar and molar areas, of which 57% of SL occurred during the first year, and only 37% of the implant joints remained stable after 3 years. Although improvements in veneering materials and laboratory protocols have decreased the frequency of SL, this mechanical complication was observed in 7% of molar and premolar restorations in a 10-year retrospective study done by Simon.^[6] The failure rate as described in that study on implants restored with single molar and premolar crowns was 4.6%; of which SL occurred in 7% of failed implants.^[6] Hence, to mitigate the problem of SL and for enhanced performance, screw designs have been revised, although the optimum design has not yet been fully established.

The process of SL has been described in two stages;^[27] the first involves slippage of the joint surfaces, when joint separating forces are large enough to cause disengagement of mating male and female threads, termed as the critical bending moment. The second phase occurs when preload has reduced to the point that external forces and vibration cause mating threads to turn, leading to the screw backing out. This signifies the importance of preload preservation, which depends on several properties of the material, such as, modulus of elasticity, composition, clamping of the parts, screw alloy, screw head design, abutment alloy, interface surface finish, presence of lubricant, size and surface area of contacting threads, pitch, screw radius, screw length, number of thread surfaces engaging, and head diameter. In addition, the implant-abutment connection has been proved to influence the torque stability due to differences in interface geometry/design, mechanical principles of function, and micromotion.^[21,22] Thus, when the long-term stability and the successful outcome of implant are given consideration, the connection between

the implant and the abutment may be of importance. With extensive research, number of configurations such as external hexagon, internal hexagon, and tapered joints have been put forward in the market.^[23]

The external butt joint was developed to provide the abutment direction on the fixture installation; and in a clinician point of view, solve problems related to the emergence profile and esthetics because of possibility to bring the porcelain of a porcelain-fused-to-metal crown much closer to the implant interface.^[23] However, it was observed that these connections were less resistant to bending movements; and on overloading, stress was transferred mainly to the screw.^[15] The other reported disadvantages were high incidence of SL and difficulty in seating abutments in deep subgingival tissues.^[7] Hence, internal connections were designed with better mechanical properties; the tightening torque being driven by the wedge effect due to the conical abutment sinking, and the load mainly supported by the internal slope of the fixture. Therefore, the stress that occurs in these abutment screws has been known to be relatively small than that in the external butt joint; the other advantages being easy abutment connection, higher stability, suitability for single tooth restoration, and higher resistance to lateral loads caused by the lower center of rotation and better force distribution.^[8,28] The internal antirotation configuration offers a greater tactile sense for judging the complete seating of abutments, which limits SL and these require less vertical restorative space.^[13] The collar around the implant connection can be favorable in the dispersion and reduction of stress, as an increase of 20% in resistance to loosening and/or distortion was reported in a study done by Covani *et al.*^[23] In two multicenter retrospective studies done by Levine *et al.* and Levine *et al.*, SL rate between 3.6% and 5.3%, far less than the numbers for the external hexagon system

was reported. Hence, internal conical connection was considered in the present study.^[29,30]

In a study by Akour *et al.* that compared trilobe design and external hex connections, the deflection, overall, and contact stress of the trilobe was lower than the external hex.^[24] Thus, trichannel has been proposed to have less potential for component fractures and as a result of its geometry prevent SL. This justifies, from an engineering standpoint, the possibility of low stress and deformation in the trichannel design because of load distribution over a larger area than the hexagonal design.^[24] Hence, in the present study, trilobe connections were selected for comparison with internal hex and for both the connection types, the slotted, flat head retaining screw design was considered, as it is more commonly used to secure the transmucosal abutment to the implant body.

The dynamics in maintenance of pretightening was influenced not only by the connection between implant and abutment but also by the abutment type (straight or angled).^[12] Hence, comparison of straight and angulated abutments, in both internal hex and trilobe connections, was considered in the present study. It is reported that after cyclic loading for 1 million times, angulated abutments showed higher removal torque values than straight abutments in external hex connection whereas in internal hex, there was no significant difference among straight and angulated abutments.^[14] This is in contradiction to the findings of the present study, in which among the implants with internal hex, angulated abutment showed slightly less percentage of damage. The contradictory observations can be ascribed to the advancement in the technical front. There are two kinds of finite element analysis (FEA), linear and nonlinear. In linear analysis, as used in previous studies, a direct correlation between stress and strain on load application will be assumed. However, the practical problems are basically nonlinear and can exist in three forms, geometric, contact, or material nonlinearity. Hence, in the present study, nonlinear analysis was considered for evaluating because of its accuracy over linear analysis.

In straight abutment models, SL is less for trilobe model when compared to conical connection with hex, as clearly appreciated from the present study. This decrease in the percentage of damage can be ascribed to the more cross-sectional area of the trilobe abutment and the ability of the design to distribute and transfer the stress in a stepwise manner. On the other hand, in the angulated models, the percentage of damage is less for conical connection with hex, when compared to trilobe. These

opposing findings can be due to the difference in the direction of the compressive load. Irrespective of the type of the abutment, the implant screw experiences stress due to initial tension created by the preload. On application of force, in straight abutments, the direction of compression is axial which decreases the stress created due to tension. However, in angulated abutments, the compression is acting at an angle, which converts some amount of force to bending movement, which adds tension to the screw, additionally increasing the stress. Thus, due to the angular force that created bending movement, trilobe might have experienced more stress compared to conical connection.

Current designs consist of a long-stem length and more threads, to reduce the friction.^[16] Hence, both short and long screws, for straight or angulated abutments with internal hex or trilobe connections were compared. The present study findings reinforced that long screws with more number of threads are always preferable, irrespective of the type of connection and angulation of the abutment, as there is a decrease in the amount of SL. This can be ascribed to the fact that the first three threads carry most of the load, with the maximal stress being concentrated between the shank and first thread.^[17]

This study stresses the fact that the implant complex is an assembly that forms a mechanical screw joint and hence, it is important for a clinician to understand the impact of implant assembly on oral function. However, the major drawback of the present study is evaluation on the simulated model, which might not be totally applicable clinically. Hence, conduction of multicentric randomized clinical trials can be the future scope to ascertain the present *in vitro* findings.

CONCLUSIONS

The present study shifts the focus of the researchers from surface coatings and lubricants for retaining the preload, to the design of implant and components. SL was more for conical connection with hex model when compared to trilobe in straight abutments; whereas trilobe showed more loosening in angulated abutments, for both vertical and oblique loads. SL was more with short screws (with 5 threads, 0.44 mm pitch) when compared to long screws (with 9 threads, 0.367 mm pitch) in both the connections, irrespective of the abutment angulation.

The study cautions the clinicians to opt proper connection based on the abutment angulation. This also highlights the significance of screw length in reducing the SL

complication; long ones with more number of threads are preferable.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

- Gaviria L, Salcido JP, Guda T, Ong JL. Current trends in dental implants. *J Korean Assoc Oral Maxillofac Surg* 2014;40:50-60.
- Chee W, Jivraj S. Failures in implant dentistry. *Br Dent J* 2007;202:123-9.
- Di Iorio D, Sinjari B, Feragalli B, Murmura G. Biomechanical aspects in late implant failures: Scanning electron microscopy analysis of four clinical cases. *J Contemp Dent Pract* 2011;12:356-60.
- Henry PJ, Laney WR, Jemt T, Harris D, Krogh PH, Polizzi G, *et al.* Osseointegrated implants for single-tooth replacement: A prospective 5-year multicenter study. *Int J Oral Maxillofac Implants* 1996;11:450-5.
- Jemt T, Pettersson P. A 3-year follow-up study on single implant treatment. *J Dent* 1993;21:203-8.
- Simon RL. Single implant-supported molar and premolar crowns: A ten-year retrospective clinical report. *J Prosthet Dent* 2003;90:517-21.
- Jemt T, Laney WR, Harris D, Henry PJ, Krogh PH Jr., Polizzi G, *et al.* Osseointegrated implants for single tooth replacement: A 1-year report from a multicenter prospective study. *Int J Oral Maxillofac Implants* 1991;6:29-36.
- Becker W, Becker BE. Replacement of maxillary and mandibular molars with single endosseous implant restorations: A retrospective study. *J Prosthet Dent* 1995;74:51-5.
- Gupta S, Gupta H, Tandan A. Technical complications of implant-causes and management: A comprehensive review. *Natl J Maxillofac Surg* 2015;6:3-8.
- do Nascimento C, Miani PK, Pedrazzi V, Gonçalves RB, Ribeiro RF, Faria AC, *et al.* Leakage of saliva through the implant-abutment interface: *In vitro* evaluation of three different implant connections under unloaded and loaded conditions. *Int J Oral Maxillofac Implants* 2012;27:551-60.
- Chen YY, Kuan CL, Wang YB. Implant occlusion: Biomechanical considerations for implant-supported prostheses. *J Dent Sci* 2008;3:65-74.
- Panza L, Boscato N, Cury AA. Evaluation of pre-tightening in abutments and prosthetic screws on different implant connections. *Rev Odontol Cienc* 2010;25:292-2.
- Tsuge T, Hagiwara Y. Influence of lateral-oblique cyclic loading on abutment screw loosening of internal and external hexagon implants. *Dent Mater J* 2009;28:373-81.
- Ha CY, Lim YJ, Kim MJ, Choi JH. The influence of abutment angulation on screw loosening of implants in the anterior maxilla. *Int J Oral Maxillofac Implants* 2011;26:45-55.
- Burguete RL, Johns RB, King T, Patterson EA. Tightening characteristics for screwed joints in osseointegrated dental implants. *J Prosthet Dent* 1994;71:592-9.
- Lang LA, Kang B, Wang RF, Lang BR. Finite element analysis to determine implant preload. *J Prosthet Dent* 2003;90:539-46.
- Alkan I, Sertgöz A, Ekici B. Influence of occlusal forces on stress distribution in preloaded dental implant screws. *J Prosthet Dent* 2004;91:319-25.
- Jingade RR, Rudraprasad IV, Sangur R. Biomechanics of dental implants: A FEM study. *J Indian Prosthodont Soc* 2005;5:18-22.
- Oswal MM, Amasi UN, Oswal MS, Bhagat AS. Influence of three different implant thread designs on stress distribution: A three-dimensional finite element analysis. *J Indian Prosthodont Soc* 2016;16:359-65.
- Martin WC, Woody RD, Miller BH, Miller AW. Implant abutment screw rotations and preloads for four different screw materials and surfaces. *J Prosthet Dent* 2001;86:24-32.
- Shenava A. Failure mode of implant abutment connections: An overview. *J Dent Med Sci* 2013;11:32-5.
- Kano SC, Binon PP, Curtis DA. A classification system to measure the implant-abutment microgap. *Int J Oral Maxillofac Implants* 2007;22:879-85.
- Covani U, Ricci M, Tonelli P, Barone A. An evaluation of new designs in implant-abutment connections: A finite element method assessment. *Implant Dent* 2013;22:263-7.
- Akour SN, Fayyad MA, Nayfeh JF. Finite element analyses of two antirotational designs of implant fixtures. *Implant Dent* 2005;14:77-81.
- Gultekin BA, Gultekin P, Yalcin S. Application of finite element analysis in implant dentistry. In: Ebrahimi F, editor. *Finite Element Analysis – New Trends and Developments*. In Tech; 2012. p. 21-54. doi: 10.5772/48339.
- Eskitascioglu G, Usumez A, Sevimay M, Soykan E, Unsal E. 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.
- McGlumphy EA, Mendel DA, Holloway JA. Implant screw mechanics. *Dent Clin North Am* 1998;42:71-89.
- Carr BT, Dersh DA, Harrison WR, Kinsel RP. When contemplating treatment involving endosseous implants, what clinical and laboratory factors most significantly affect your choice of an implant system? *Int J Oral Maxillofac Implants* 2001;16:123-7.
- Levine RA, Clem DS 3rd, Wilson TG Jr., Higginbottom F, Solnit G. Multicenter retrospective analysis of the ITI implant system used for single-tooth replacements: Results of loading for 2 or more years. *Int J Oral Maxillofac Implants* 1999;14:516-20.
- Levine RA, Clem DS 3rd, Wilson TG Jr., Higginbottom F, Saunders SL. A multicenter retrospective analysis of the ITI implant system used for single-tooth replacements: Preliminary results at 6 or more months of loading. *Int J Oral Maxillofac Implants* 1997;12:237-42.