DENTAL IMPLANT MATERIALS, IMPLANT DESIGN, AND ROLE OF FEA- A BRIEF REVIEW

Duraisamy Velmurugan[1], Alphin Masilamani Santha[2], Sachin Gaurishankar Sarate[3]

[1]Research Scholar, Department of Mechanical Engineering, SSN College of Engineering, Kalavakkam, Chennai.
[2]Associate Professor, Department of Mechanical Engineering, SSN College of Engineering, Kalavakkam, Chennai.
[3]Doctor, Department of Biomedical Engineering, SSN College of Engineering, Kalavakkam, Chennai.

ABSTRACT

BACKGROUND
A dental implant is utilised to hold the counterfeit tooth into its legitimate position in the human jaw. It fills the need of characteristic root which is there in a normal tooth. Implant design, implant stability, materials used in dental implants are the main factors required for the long-haul accomplishment of a dental implant.

The aim of this article is to give a brief review on dental implant materials, implant design, numerical approach used in dental implants by the researchers over the years.

KEYWORDS
FEA, Implant Design, Implant Materials.

HOW TO CITE THIS ARTICLE: Velmurugan D, Santha AM, SarateSG.Dental implant materials, implant design, and role of FEA- A brief review.J. Evolution Med. Dent. Sci. 2017;6(44):3487-3492, DOI: 10.14260/Jemds/2017/753

BACKGROUND
Logical investigation of memorable confirmation demonstrates that people have tried to supplant missing teeth with root shape inserts for a great many years.[1] Four thousand years back in old China, for supplanting lost teeth, bamboo pegs were utilised. Bamboo pegs take advantage of the bone to supplant lost teeth. Valuable metals have been utilised as a part in old Egypt to make a likewise formed peg. In some Egyptian mummies, transplanted human teeth were found. These teeth were made of ivory.[2-3] Advancement of dental inserts achieved its new stature in the early part of the twentieth century. More implants were made of an assortment of materials. The Greenfield introduced the best implant arrangement in 1913.[4] Bothe, Beaton and Davenport utilised titanium as a first implantable material in 1940.[5] Bothe et al were the primary analysts to mark the name osseointegration. Osseointegration was promoted later on by Per-Ingvar Brånemark. The Achievement rate of osseointegration relies upon the material which is utilised for making an implant. Titanium poles were implanted in rabbits by Gottlieb Leventhal in 1951. The result of this persuaded titanium is the perfect material for surgery.[6] Present day dental implant turned into a critical use of choice in the substitution of harmed teeth or loss of characteristic teeth since 1960. The quantity of implant plans and number of implant businesses are accessible nowadays. At present implants are accessible with various distances across, lengths and diverse shapes and sizes. Implant outlines are accessible within thread frames and furthermore without thread shapes.[7]

Financial or Other, Competing Interest: None.
Submission 27-04-2017, Peer Review 21-05-2017,
Acceptance 27-05-2017, Published 01-06-2017.
Corresponding Author:
Alphin Masilamani Santha,
Associate Professor,
SSN College of Engineering,
Kalavakkam, Chennai-603110.
E-mail: alphin@aol.in
DOI: 10.14260/jemds/2017/753

Biomechanical thought is utilised to decide the long haul achievement of the dental implant. It depends on the strengths they need to bolster.

The aftermath of concentrated constraint prompts to break of implant segments, or loss of bone neighbouring the implant.[8] Biologic components and mechanical elements assume an imperative part to find the inserts. Inserts have low disappointment rates when they are set in more grounded and thicker bone, for example base jaw, and have high disappointment rates when they are put in lower thickness bone, for example some portion of the upper jaw. The force on implants likewise increments when individuals granulate their teeth, this may prompt to a probability of disappointments.[9]

This article review the writing on materials utilised as a part of dental implant, dental implant design, and numerical approach utilised as a part of dental inserts.

Implant Materials
Brånemark (1960) introduced oral implants and it became a reliable treatment option for the replacement of missing teeth.[10] Dental implant material properties such as physical and chemical properties are well reported and documented. Properties of materials may contain the microstructure of the implant, its surface characteristics and design factors.[11] A perfect implant material must have biocompatibility, adequate strength, toughness, wear resistance and corrosion resistance.[11,12] Material which is used for the fabrication of dental implants are categorised according to their chemical composition and biological responses. The design principles of the implant should be compatible with physical properties of the dental implant material.[13] Metals, ceramics or polymers are some commonly used materials to make an implant in dentistry. Dental implants fall into any of the abovementioned group.

Metals and Ceramics
For dental implants, metals are selected based on a factor involved with its properties. These properties are belonging to its biomechanical characteristics, surface finishing characteristics and its machining characteristics. Metals like Co-Cr, stainless steel, gold are outdated in the dental implant industry. The currently available dental metals are Titanium

and its alloys, Zirconium. But some of the dental implant components like abutment, abutment screws, and various attachments are made of gold alloys, Co-Cr alloys and stainless steels.[14]

Titanium is the material of choice for intraosseous applications because it has typical properties like high passivity, resistance to chemical dose. Also, it has ability to repair itself if damaged. Its modulus of elasticity 116 GPais compatible with that of bone and titanium oxide.[15] However, titanium which is a typical material for dental implants has a few drawbacks. Titanium is unaesthetic in the frontal area.[16] Ti-6Al-4V, Ti-6Al-4V extra low interstitial are commonly used materials. These detriments of titanium prompted to new implant innovation.

Ceramic implants are being developed to overcome the above said drawbacks.[17] As a result of this zirconia is used as another material for dental inserts. Contrasted with metallic components zirconia demonstrates least particle discharge and they are thought to be dormant in the body.[18] Zirconia has a tooth like shading, great mechanical properties and subsequently great biocompatibility. In this way it is by all accounts an appropriate dental material.[19] The utilisation of zirconia inserts maintains a strategic distance from this inconvenience and acquiesces to the demand of numerous patients for without metal inserts. The material additionally gives high quality, crack sturdiness, and biocompatibility.[20] Table 1 indicates materials used for fabricating endosseous dental implants.[21-23]

Polymers

A variety of polymers have been utilised as dental implant materials.[24] A portion of the polymer materials are polymethylmethacrylate, polytetrafluoroethylene, polyethylene, polysulfone, polyurethane. When polymer acts as coating layer, inferior mechanical properties, lack of adhesion to living tissues, and adverse immunologic reactions are eliminated.[24-28] Today, polymeric materials are constrained to the assembling of shock retaining segments joined into the superstructures bolstered by inserts.[29]

An extensive variety of biomaterials are as of now being used for inserts. It gets to be distinctly important to choose adept biomaterial. Proper determination of biomaterials straightforwardly impacts clinical achievement and life span of inserts. The current materials like bioceramics and composite biomaterials which are under thought and examination have a promising future.

Implant Design

Implant configuration refers to the three-dimensional structure of the implant. To depict the three-dimensional structure frames, shape, setup, surface, full scale structures and large scale anomalies have been utilised. Success rate of implant depends on two factors, namely implant design and surface conditions. Although implants have been used for close to a half century with incredible accomplishment, there are couple of rules that depict when or where to utilise the distinctive sorts of inserts. Comprehension and utilising biomechanical hypotheses that influence endosseous implant configuration may enhance the accomplishment of these inserts in different load conditions and may permit the clinician to better apply these rules, with a change in achievement rates. Many interrelated components are included for outlining dental inserts. A portion of the elements are geometry of the implant, mechanical properties and long-haul steadiness. There is no standard design to measure the ability of the dental implant to exchange load to encompassing biologic tissues.[30] Along these lines the essential plan goal is to oversee biomechanical load. Different design of implant leads to show variation in stress distribution. The figure 1 shows variation of stress against different sizes of pitch.

Dental Implant configuration can be ordered under the accompanying headings: Implant design classification, Plan and creation of Redid Dental Inserts and effect of thread pattern. Large scale outline and small scale configuration are two central points contributed for implant plans known as macro and microdesign respectively. Thread pattern and thread design goes under macrodesign. Materials for inserts, surface morphology and surface coating are a portion of the variables centred under microdesign.[31] This part of the review attempts to integrate information in dental implant designsuch as selection of implant diameter, length and shape of the implants.

Implant Diameter

Implant diameter is the measurement measured from the peak of the largest thread to a similar point on the inverse side of the implant. The outside dimension of the thread is measured by diameter. Since an assortment of implant widths and stages are accessible, a wide-stage implant is not generally unplanned with an expanded diameter of the implant thread. As of now implants vary in diameter from 3 to 7 mm. The necessities for implant diameter depend on both surgical and prosthetic prerequisites. Width of implant is designed to gain maximum stability. From a biomechanical point of view utilisation of wider implants permits engagement of a maximal measure of bone, and distribution of stress is improved theoretically.[32] Distribution of the stress depends on diameter of the implant. Distribution of stress varies with respect to implant design. The figure 2 shows variation of stress against different designs of implant.

Implant Length

It is the length from the platform to the peak of implant. Length of the implant was delegated short, medium and long. The scope of short implant length was from 6-9 mm. The medium implant length lies between 10-12 mm and long implant length ranges from 13-18 mm. In spite of the fact that a direct connection amongst length and achievement rate has not been confirmed, the studies show that shorter inserts have literally brought down achievement rates.[33] The 7 mm implant length prompts to more dissatisfaction rate while comparing with other implant lengths.[34] An investigation of fixed single-unit rebuilding efforts showed that a connection between implant length and achievement may not exist, particularly more than 13 mm in length.[35] No connection between introductory versatility and implant length has been established[36] and mechanical examinations have bolstered the view that expanding the implant length may just build achievement rate to a specific extent.[37]

Implant Shape

The states of dental inserts have changed from customary root structures to sharp edge and subperiosteal designs.[38] The state of dental inserts has been a standout amongst the most challenged parts of outline among the endosseous frameworks and may affect implant biomechanics.[39] Most current implant frameworks are accessible as strong or hollow screws or cylinders. Some implant manufacturers give implants in both shapes and suggest their utilisation in various sorts of bone. Among screw shaped implants, extensive modification has been made to the crestal and apical bit of the implant to expand self-tapping. Different outlines have been created to impersonate root life structures and consolidate a ventured round and hollow plan, comparable to the tooth root at both cervical and apical finishes. These stepped cylindrical implants demonstrate more even stress dispersal contrasted with tube shaped or decreased implants.[40]

Numerical Approach Used in Dental Implants

Finite Element Analysis (FEA) has turned into an undeniably valuable tool for the estimate of the impacts of stress on the implant. The loads from vertical and transverse direction leads to axial force and bending moments and result of this stresses are induced in implants. A key component for the achievement or disappointment of a dental implant is the way in which stresses are exchanged to the encompassing bone. The researchers used FEA to know how the stresses are distributed in the implants.

Role of FEA in Biomechanical System

For issues including convoluted geometries, it is exceptionally hard to accomplish an exact solution. In this way, the utilisation of numerical techniques, for example, FEA is required. FEA is a strategy for getting an answer for a complex mechanical issue by separating the issue area into an accumulation of considerably littler and less complex areas. Since the parts in a dental implant bone framework are greatly unpredictable geometrically, FEA has been seen as the most appropriate device for examining them. The advancement of FEA began in the mid-1960s to solve problems associated with aerospace industry. However, application of FEA stretched out to solve heat transfer problems, fluid stream. The use of FEA in implant dentistry began in 1976.[41] Stress distribution is performed in an implant which has a place with single tooth to know the impact of parameters and geometry of the implant.[42-44] 3D investigation of FEA performed by Borchers and Reichart.[45] The foremost trouble in recreating the mechanical conduct of dental inserts is the displaying of human bone tissue and its reaction to connected mechanical device. Certain suspicions should be made to make the displaying and understanding procedure conceivable. The unpredictability of the mechanical portrayal of bone and its collaboration with implant frameworks has constrained creators to make significant disentanglements. A few suspicions impact the precision of the FEA comes about essentially. These include: (1) itemised geometry of the bone and implant to be modeled, (2) material properties, (3) limit conditions[46] and (4) the interface amongst bone and implant.[47] Table 2 indicates summary of literature used in FEA.

Material properties enormously impact the anxiety conveyance in a structure. In most announced reviews, the assumption is made that the materials are homogeneous and linear and that they have flexible material conduct described by two material constants of Young's modulus and Poisson's proportion. The design methodology includes complete factors like threads nature on surface of the implant and different bone properties.[48] Most FEA studies demonstrating the mandible set the limit conditions as settled. The utilisation of interminable components can be a decent approach to model limit conditions.

In outline, stress dispersion relies on upon assumptions made in demonstrating geometry, material properties, limit conditions, and the bone–implant interface. To get more exact stress value, progressed computerised imaging procedures can be connected to demonstrate the bone geometry all the more practically; the anisotropic and non-homogenous nature of the material must be considered; and limit conditions must be precisely treated with the utilisation of computational displaying methods.

Implant Material	Common Name
I. Metals	
Titanium	cpTi
Titanium Alloy	Ti6Al4V
Stainless steel	SS, 316 L SS
Co-Cr Alloy	Vitallium, Co-Cr-Mo
Cold Alloys	
Tantalum	Ta
II. Ceramics	
Alumina	Al_2O_3, amorphous or single crystal sapphire (Kyocera)
Hydroxyapatite	HA,Ca_{10} $(PO_4)_{10}$ $(OH)_2$
Beta-Tricalcium Phosphate	B-TCP $Ca_3(PO_4)_2$
Carbon	Vitreous, low temperature isotropic (LTI), ultra-low temperature isotropic (ULTI)
Carbon –silicon	C-Si
Bio-glass	$SiO_2/CaO/Na_2O/P_2O_5$
III. Polymers	
Polymethylmethacrylate	PMMA
Polytetrafluoroethylene	PTFE
Polyethylene	PE
Polysulfone	PSF
Polyurethane	PU

Table 1. Materials used in Dental Implants

Author	Objectives	Material and Methods	Conclusions
Weinstein AM et al 1975	The distribution of stress and magnitude was investigated	Porous rooted Co-Cr-Mo alloy Dental Implants. 17 mm long and 5.5 mm diameter	High concentration of stresses occurs at the lower end of the implant
Atmaram GH et al 1979	Stress distribution within and around the implants were determined.	-5 different materials (dentin, vitallium, titanium, vitreous carbon and polymethyl methacrylate (PMMA) - 3 different implant geometry (Conical, Natural tooth root implant, Cylindrical implant) - Ankylosed single-tooth implants were used.	-Most favourable stress distributions at cylindrical implant. -High reduction of stresses is possible while using non-biologic material.
Atmaram GH et al 1979	Biomechanical design of cylindrical implant was optimised	-Cylindrical root geometry implant. -FEA method used.	Significant reduction in high alveolar stress while providing longer length for cylindrical implants.
S.D. Cook et al 1982	To develop a Finite element computer model for porous rooted dental implants.	-Cylindrical design implant -Co-Cr-Mo alloy used	Direct bone-to-implant interface may not be a good representation for a porous rooted implant
Borchers L et al 1983	The distribution of stress in the bone surrounding implant was determined.	-Anchor type endosteal implant -Ceramic (Al_2O_3)	Crestal region of the alveolar bone, High stress peaks were calculated
Reinhardt RA et al 1984	Principal periodontal ligament stresses in primary and Secondary occlusal trauma was calculated.	Labiolingual cross sectional model of the tooth, periodontal ligament, gingiva, and alveolar bone was developed	Areas of greatest compressive stress near the Alveolar crest
Maeda Y et al 1989	To evaluate the relative effects of rebasing and the position of occlusal loading on the compressive strains	A 2D plane-stress finite-element simulation model was used.	A complete denture is related to compressive stresses transmitted to the bone.
Rieger MR, et al 1990	Stress magnitudes and contours in the bone surrounding were determined.	Six post-type endosseous implants were selected.	-Denar implants leads to higher stresses - The Miter and RBT 411 implants had good bone stress distribution.
Akpinar I et al 1996	Displacement of nature teeth was investigated	-Two-rigid implant (hollow and solid screw)design used	-Solid screw implant is more suitable.
Van Oosterwyck H et al 1998	Stress, strain distribution around an implant were studied	-Solitary Brånemark -Cylindrical volume implant used	-Bone loading patterns are highly sensitive. -For FE models of the human jaw stresses are important.
Bulent Ekici 2002	Effect of washer in implant on the loosening condition was determined.	3D model of standard Brånemark single implant system was used.	Washer has an important effect against loosening. Washer does not affect the application of preload.
Canan Hekimoglu et al 2004	To compare strains induced around a natural tooth opposing an implant with strains around occluding implants under static and dynamic loads.	Nobel Biocare, 5 mm diameter and 13 mm length was used.	Under static and dynamic loads, strain magnitudes around a natural tooth were significantly lower than that of an opposing implant and occluding implants in the contralateral side.
Barıs, Simsek et al 2005	To evaluate the effects of different inter-implant distances on stress distribution in the bone around the endosseous titanium implants	ITI implant system was used	The 1.0 cm of inter-implant distance is the optimum distance for two fixture implantation

Oguz Kayabası a et al 2006	Static dynamic and fatigue behaviours of the implant are Investigated.	ITI implant was used, 4.1 mm diameter and 12 mm long	The maximum stress values did not reach the yield strength of abutment and prosthetic screws of the Implant and it seems that the implant is durable in all conditions, static and dynamic loading
Chih-Ling Chang et al 2012	Redesign of the implant.	Implant was designed using topology optimisation method.	The new implant was shaped by topology optimisation and decreased the volume of the traditional implant by approximately 17.9%

Table 2. Summary of Literature used in FEA

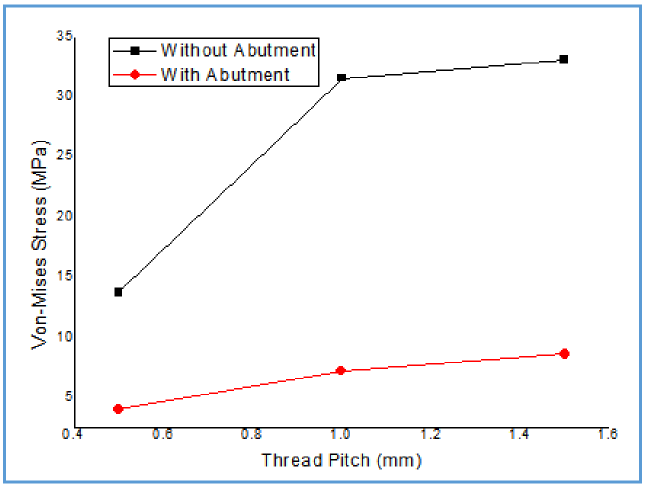

Figure 1. Maximum stress on the bone element of different pitch

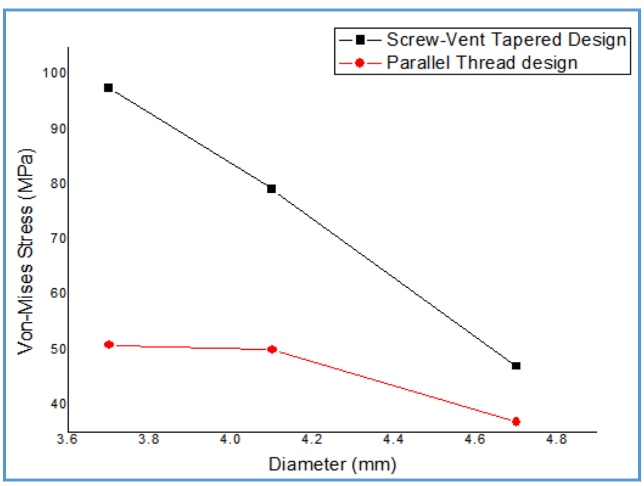

Figure 2. Von-Mises stress in implant design based on diameter.

CONCLUSION
This paper briefly reviews the materials used in dental implant, dental implant design, and numerical approach used in dental implants, dental implant stability. For an optimum implant design, biological, mechanical, physical properties should be considered. Since number of implant designs are available nowadays, operators should select current implant design based on the requirements. In numerical approach point of view, FEA has been used effectively to predict the biomechanical characteristics of any dental implant system. FEA is a powerful computational device that has been adjusted from the designing field to dental implant biomechanics.

REFERENCES

[1] Carl ME. Contemporary implant dentistry. 3rd edn. St. Louis, Missouri: Mosby Elsevier 2007.

[2] Balaji SM. Textbook of oral and maxillofacial surgery. 2nd edn. New Delhi: Elsevier India 200:301-02.

[3] Kenneth AJ. Phillips science of dental materials. 11th edn. St. Louis, Missouri: Saunders Elsevier 2003; p. 6.

[4] Greenfield EJ. Implantation of artificial crown and bridge abutments. Dental Cosmos 1913;55(4):364-9.

[5] Bothe RT, Beaton LE, Davenport HA. Reaction of bone to multiple metallic implants. SurgGynecol Obstet 1940;71:598-602.

[6] LeventhalGS, Titanium, a metal for surgery. J Bone Joint Surg Am 1951;33-A(2):473-4.

[7] Noorthoek DR. Macroscopic and microscopic dental implant design: a review of the literature. MS thesis, Graduate School of the University of Florida, 2013.

[8] Patrick P. Optimal implant positioning and soft tissue management for the Branemark system (in English). Germany: Quintessence Books 1995:21-33.

[9] Per-Ingvar B.Zarb GA. Tissue-integrated prostheses (in English). Berlin, German: Quintessence Books1989.

[10] Brånemark PI, Hansson BO,Adell R,et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J PlastReconstrSurgSuppl1977;16:1-132.

[11] Smith DC. Dental implants: materials and design considerations. IntJProsthodont 1993;6(2):106-17.

[12] Parr GR, GardnerLK,TothRW. Titanium: the mystery metal of implant dentistry. Dental materials aspect. J Prosthet Dent 1985;54(3):410-4.

[13] Sykaras N,Lacopino AM, Marker VA,et al. Implant materials, designs and surface topographies: their effect on osseointegration. A literature review. Int J Oral Maxillofac Implants 2000;15(5):675-90.

[14] Ravnholt G. Corrosion current and pH rise around titanium coupled to dental alloys. Scand J Dent Res 1988;96(5):466-72.

[15] Kasemo B, Lausmaa J. Metal selection and surface characteristics. In: Brånemark P-I, Zarb GA, Albrektsson T. eds. Tissue-Integrated prostheses: osseointegration in clinical dentistry. Chicago: Quintessence 1985:99-116.

[16] Heydecke G, Kohal R, Gläser R. Optimal esthetics in single-tooth replacement with the Re-Implant system: a case report. Int J Prosthodont 1999;12(2):184-9.

[17] Kohal RJ, Klaus G. A zirconia implant-crown system: a case report. Int J Periodontics Restorative Dent 2004;24(2):147-53.

[18] Sennerby L, Dasmah A, Larsson B, et al. Bone tissue responses to surface-modified zirconia implants: a histomorphometric and removal torque study in the rabbit. Clin Implant Dent Relat Res 2005;7(Suppl 1):S13-S20.

[19] Depprich R, Zipprich H, Ommerborn M, et al. Osseointegration of zirconia implants compared with titanium: an in vivo study. Head Face Med 2008;4:30.

[20] Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials 1999;20(1):1-25.

[21] Williams DF. Implants in dental and maxillofacial surgery. Biomaterials 1981;2(3):133-46.

[22] Lemons JE. Dental implant biomaterials. J Am Dent Assoc 1990;121(6):716-9.

[23] Craig RG. Restorative dental materials. 9th edn. C.V. Mosby: St. Louis, MO, USA 1993; p. 169.

[24] Glantz PO. The choice of alloplastic materials for oral implants: does it really matter? Int J Prosthodont 1998;11(5):402-7.

[25] Carvalho TL, Araujo CA, TeofiloJM, et al. Histologic and histometric evaluation of rat alveolar wound healing around polyurethane resin implants. Int J Oral MaxillofacSurg 1997;26(2):149-52.

[26] Lemons JE. Dental implant biomaterials. J Am Dent Assoc 1990;121(6):716-9.

[27] Meijer GJ, StarmansFJ, de Putter C, van Blitterswijk CA. The influence of a flexible coating on the bone stress around dental implants. J Oral Rehabil 1995;22(2):105-11.

[28] Meijer GJ, Dalmeijer RA, de Putter C, et al. A comparative study of flexible (polyactive) versus rigid (hydroxyapatite) permucosal dental implants. II. Histological aspects. J Oral Rehabil 1997;24(2): 93-101.

[29] Meijer GJ, Heethaar J, Cune MS, et al. Flexible (polyactive) versus rigid (hydroxyapatite) dental implants. Int J Oral MaxillofacSurg 1997;26(2):135-40.

[30] Kawahara H. Cellular responses to implant materials: Biological, physical and chemical factors. Int Dent J 1983;33(4):350-75.

[31] Chapman RJ, Kirsch A. Variations in occlusal forces with a resilient internal implant shock absorber. Int J Oral Maxillofac Implants 1990;5(4):369-74.

[32] Misch CE. Density of bone: effect on treatment plans, surgical approach, healing, and progressive bone loading. Int J Oral Implantol 1990;6(2):23-31.

[33] Abuhussein H,Pagni G, Rebaudi A, et al. The effect of thread pattern upon implant osseointegration.Clin Oral Implant Res 2009;21(2):129-36.

[34] Ivanoff CJ, Sennerby L, Johansson C, et al. Influence of implant diameters on the integration of screw implants. An experimental study in rabbits. Int J Oral MaxillofacSurg 1997;26(2):141-8.

[35] Winkler S, Morris HF, Ochi S. Implant survival to 36 months as related to length and diameter. Ann Periodontol 2000;5(1):22-31.

[36] Wyatt CC, Zarb GA. Treatment outcomes of patients with implant supported fixed partial prostheses. Int J Oral Maxillofac Implants 1998;13(2):204-11.

[37] Eckert SE, Koka S, Wolfinger G, et al. Survey of implant experience by prosthodontists in the United States. J Prosthet Dent 2002;11(3):194-201.

[38] Douglass GL, MerrinRL. The immediate dental implant. J Calif Dent Assoc2002;30(5):362-5, 368-74.

[39] Lum LB. A biomechanical rationale for the use of short implants. J Oral Implantol 1991;17(2):126-31.

[40] Kurtzman GM, Schwartz K. The subperiosteal implant as a viable long term treatment modality in the severely atrophied mandible: a patient’s 40-year case history. J Oral Implantol 1995;21(1):35-9.

[41] Lin S, Shi S, LeGerosRZ, et al. Three-dimensional finite element analyses of four designs of a high-strength silicon nitride implant. Implant Dent 2000;9(1):53-60.

[42] Holmgren EP, Seckinger RJ, Kilgren LM, et al. Evaluating parameters of osseointegrated dental implants using finite element analysis–a two dimensional comparative study examining the effects of implant diameter, implant shape, and load direction. J Oral Implantol 1998;24(2):80-8.

[43] Weinstein AM, KlawitterJJ, Anand SC, et al. Stress analysis of porous rooted dental implants. J Dent Res 1976;55(5):772-7.

[44] AtmaramGH, Mohammed H. Stress analysis of single-tooth implants. I. Effect of elastic parameters and geometry of implant. Implantologist 1983-84;3(1): 24-9.

[45] AtmaramGH, Mohammed H. Stress analysis of single-tooth implants. II. Effect of implant root-length variation and pseudo periodontal ligament incorporation. Implantologist 1983-84;3:58-62.

[46] Mohammed H, AtmaramGH, Schoen FJ. Dental implant design: a critical review. J Oral Implantol 1979;8(3): 393-410.

[47] Borchers L, Reichart P. Three-dimensional stress distribution around a dental implant at different stages of interface development. J Dent Res 1983;62(2):155-9.

[48] Van Oosterwyck H, Duyck J, SlotenVJ, et al. The influence of bone mechanical properties and implant fixation upon bone loading around oral implants. Clin Oral Implants Res 1998;9(6):407-18.