Original Article

Biomechanics of dental implants: A FEM study

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Biomechanics comprises all kinds of interactions between tissues and organs of the body and the forces acting on them. Biomechanics comprises the response of the biologic tissues to the applied loads.

Aims and objectives: Attempt has been made to understand the basics of biomechanics with a view on finite-element stress distribution analysis in three situations namely:

1. To compare the stress distribution in a single implant with the narrow ceramic occlusal table and wide ceramic occlusal table.
2. To compare the stress distribution in two implants supporting a three-unit bridge, one model with implants placed parallel to each other and the other with one implant placed in angular position to the other.
3. To compare the difference in the stress distribution in six implants and four implants supporting mandibular over-denture.

Materials and Methods: The three-dimensional (3-D) finite-element mesh model was modeled with the standard dimension of the implant with 11-mm long and 4-mm wide using the software package 'NISA'.

Results and Discussion: The design, number and placement of implants play an important role.

Summary and Conclusion: The basic principles of biomechanics must be respected.

Key words: Angulated implants, biomechanics, biomechanics of dental implants, FEM study, FEA study, four *vs* six implants, tripodisation, implant-supported over-denture, occlusal table, stress-distribution analysis

Biomechanics comprises of all kinds of interactions between tissues and organs of the body and the forces acting on them. Biomechanics comprises the response of the biologic tissues to the applied loads.[1]

In many instances biomechanics can quite literally make (or) break an implant case. Usually, in any structure subjected to functional loads, there may be situations leading to overload and subsequent complications. When we come to the biomechanics of dental implants, here the implant treatment defines a structure based on both the biologic tissues (bone) and the mechanical components (implant and superstructure). So the biomechanics of dental implants concerns the response of biologic tissues to the applied loads.

Hence, the success of dental implants depends on the understanding of the basic biomechanics and the following are the factors that influence the biomechanics of dental implants.[2]

1. The number and placement angulation of implants in the patient's mouth.
2. The significance of implants angulation with respect to the occlusal plane.
3. The fracture of prosthetic part of implants.
4. The property of connecting natural tooth to implants.
5. The pros and cons of screw shaped *vs* cylindrical-shaped implants.
6. The role of mechanical loading on the status of bone around the implant.

These fundamental concepts and principles of biomechanics are very much essential as they relate to the long-term success of dental implants.

In this perspective, attempt has been made to understand the basics of biomechanics with a view on finite-element stress distribution analysis in three situations namely:

1. To compare the stress distribution in a single implant with the narrow ceramic occlusal table and

wide ceramic occlusal table.
2. To compare the stress distribution in the two implants supporting a three-unit bridge, one model with implants placed parallel to each other and the other with one implant placed in angulation to that of the other.
3. To compare the difference in the stress distribution in six implants supported mandibular over-denture and four implants supported mandibular over-denture.

MATERIALS AND METHODS

The three-dimensional (3-D) finite-element mesh was modelled, with the standard dimension of the implant with 11-mm long and 4 mm wide using the software package for finite-element study 'NISA', in Bapuji Institute of Engineering and Technology, Davangere, Karnataka, India.

(1) finite-element mesh model was constructed with narrow Ceramic Occlusal table and the wide Ceramic Occlusal table.
(2) finite-element mesh model was constructed with two implants supporting a three-unit bridge, one model with implants placed parallel to each other and the other with one implant placed in angulation to the other.
(3) finite-element mesh model was constructed with four implants supported mandibular over-denture and six implants supported mandibular over-denture. The mandibular meshwork was constructed considering the radius of the mandible taken as 22.5 mm, with the arc of 112.5° representing the distance roughly equal to that between the mental foramina in the human mandible [Table 1].[1,3]

RESULT AND DISCUSSION

Biting force

Under normal circumstances, single free-standing tooth or implant is commonly subjected to chewing forces that is usually compressive, but certainly not exclusively compressive, as they are also subjected to tensile and the shear forces.

Owing to the inclined occlusal surfaces of the crown, a food particle typically does not make contact with the crown in such a way that the contact force acts perfectly parallel to the long axis of the tooth (or) implant.

Table 1: The elastic modulus and poisons ratio for oral tissues and prosthetic material taken in FEA evaluation[3]

Material	Modulus of elasticity (MPa)	Poisons ratio (υ)
Cortical bone	13, 700	0.30
Cancellous bone	7, 930	0.30
Titanium	102, 195	0.35
Feldspathic porcelain	82, 800	0.35

Here is an example showing a free-standing implant being acted on by force, which is slightly angled with respect to the long axis of an implant [Figure 1]. There are axial components of the forces, which tend to compress (or) push the implant into the bone.

At the same time, there are lateral force components also existing, which tend to push the tooth sideways and tip it to a point B. so there comes the factor of MOMENT, the implant that is subjected on.[2]

Two clinically significant points about this are as follows:[2]

1. The bone implant interface has to supply the counterbalancing moment to keep the implants in static equilibrium.
2. The implant hardware, if contains screw joints, must be able to withstand the moment that is experienced by the implant.

The moment (or) the leverage factor is also greater in situations in which the occlusal table of the crown is substantially larger than the diameter of the fixture, leading to possible bending in all directions [Figure 2].

The larger dimension of the occlusal table of the crown and higher cuspal inclinations lead to relatively higher magnitudes of the transverse component.

Here the position of the lateral excursive contact determines the position of the force; i.e. the more lateral the contact, greater the leverage.

So every attempt should be made for centering the occlusal contacts, so that the lever arm will be reduced.

Here is one finite element study, where I have made an attempt to find the difference in the stress distribution in a single implant with narrow ceramic occlusal table and wide ceramic occlusal table.

The model with narrow ceramic occlusal table was divided into 2160 elements and 2595 nodes and the model with wide ceramic occlusal table was divided into 2172 elements and 2602 nodes.

The stress distribution analysis showed the magnitude of stress at element 1524 as 64 MPa in model with narrow ceramic occlusal table and 84 MPa in model with wide ceramic occlusal table [Figure 3].

Hence careful consideration of the design of the occlusal surfaces and the contact pattern, with lesser cusp inclines is therefore important for limiting the stresses on the implant and the bone.

Furthermore, it is very important to diagnose any parafunctional habits as such habits may contribute to the bending overload. Observations in the clinical findings of excessive occlusal wear and/or a history of parafunctions of the natural teeth, with changes of enamel or veneering material should be considered as the indicators of increased overloading.

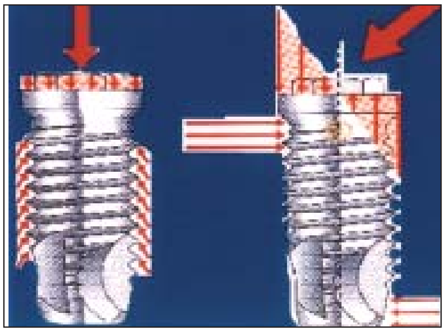

Figure 1: Representative diagram showing implants being subjected not only to compressive, but also to oblique tensile and shear stress

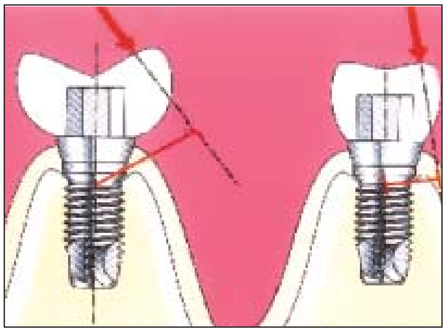

Figure 2: Representative diagram showing implant with wide ceramic occlusal table with lateral force component away from the long axis of implant and narrow ceramic occlusal table with lateral force component towards the long axis of an implant

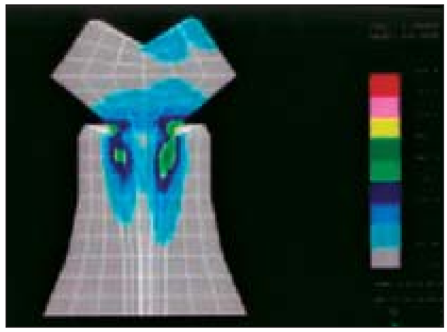

Figure 3: Finite-element stress distribution analysis with maximum stress concentration at the cervical angle of implant measuring about 84 MPa in 1524 elements in wide ceramic occlusal table

Does angulation of the implants have any effect' on the stresses in the bone

Angulation of the fixture, in certain situations may lead to better anchorage and/or better implant position. It does not lead to the increase loading, as the superstructure will counteract angulation in the implant as defined by the prosthesis long axis and the implant direction [Figure 4].

As long as the inclination of the position of fixture head or abutment head is minimal within the range of 12-15°, the stress distribution in the implant is comparatively very similar to that of the parallely placed implant.[3]

Here is a finite element model to compare the stress distribution in two implants supporting a three unit bridge, one model with implants placed parallel to each other, an the other with one implant placed in angulation to that of the other.

The FEA model with two implants placed parallel to each other was divided into 6834 elements and 6840 nodes and the FEA model with one implant placed at 12° angulation to that of the other was divided into 6912 elements and 6924 nodes.

The stress distribution analysis showed the magnitude of stress at element 4536 as 92 MPa in model with implants placed parallel to each other and 102 MPa in model with one implant paced in angulation to that of the other [Figures 5-7].

The aim thus should be to place the fixture head as closely as possible to the direction of the forces, reducing the lever arm and the bending movement.

Similarly, in the case of three-unit prostheses, the ideal situation from a biomechanical point of view is three implants placed in a slightly curved configuration, with the middle implant offset a minimum of 2-3 mm in the buccolingual direction.[4] This tripod implant configuration allows the load transfer to bending forces to be mostly axial, minimizing the stress level [Figure 8].[5]

It is estimated that the stress level will be reduced approximately 50% by tripodisation, compared to a straightline configuration.[4,6]

Suppose a patient presents with an edentulous jaw having enough space to allow four or six implants in the anterior. It is said to be four or six implants can be placed. If the mean distance between the two mental

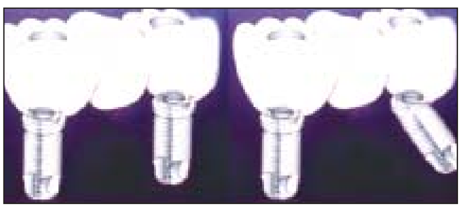

Figure 4: Representative diagram showing two implants supported fixed partial denture with (a) two implants placed parallel to each other and (b) the other with one implant placed in 12° angulation to that of other

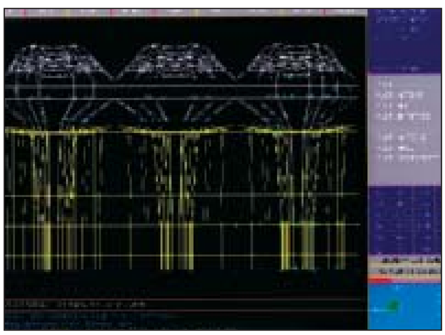

Figure 5: Finite-element model with 6834 elements and 6840 nodes showing two implants support fixed partial denture with implants placed parallel to each other

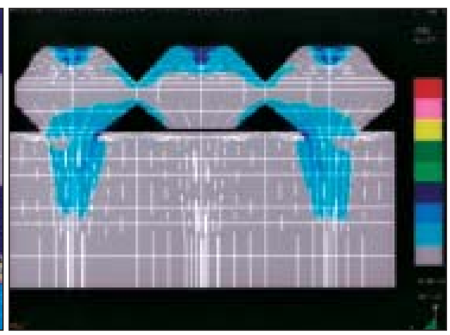

Figure 6: Finite-element stress distribution analysis of two implants supported fixed partial denture with two implants placed parallel to each other

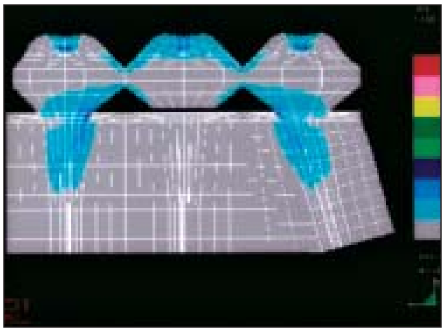

Figure 7: Finite-element stress distribution analysis of two implants supported fixed partial denture with one implant placed in 12° angulation to that of the other

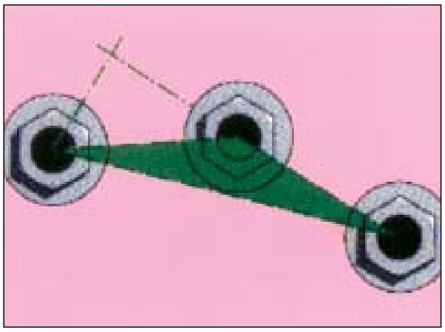

Figure 8: Diagram showing to illustrate tripodisation

Figure 9: Illustrative photograph showing four implants supported mandibular over-denture with implants placed between two mental foramina

foramina is 47 mm and when the distance from centre of one implant to that of the adjacent implant is taken to be 7 mm at least, it is said that up to six implants can be placed [Figure 9].[1,6]

Consider the case of six *vs* four implants symmetrically distributed about the midline of the mandible over the same arc of 112.5°. If the radius of mandible is taken to be to 22.5 mm, the arc of 112.5° represents the distance roughly equal to that between the mental foramina in the human mandible.[7] So the question arises, whether to place four or six implants and is there any difference if we place four or six implants in this case [Figure 10].

Here is a finite-element model to compare the difference in the stress distribution in six implants supported mandibular overd-enture and four implants supported mandibular over-denture.

The FEA model of six implants supported mandibular over-denture was divided into 48176 elements and 48464 nodes, the FEA model of four implants supported mandibular over-denture was divided into 48164 elements and 48434 nodes [Figures 11, 12].

When comparison of the forces are made in two situations, the results showed that the magnitude of the forces on the most distal abutments are similar in the four-implant and the six-implant cases. This means that there is only a slight difference between using four implants instead of six to support prosthesis, as long as the four implants are spaced out over the same arc as the six implants.

1. For the same total arc length, the interimplant spacing in the four implants is much larger than in the six-implant case.
2. For the same total arc length, when the implants either four or six are spaced out equally, the length of the cantilever is almost the same in both the cases.

Hence, when the distribution and density of stress on prosthesis supported by six implants are compared with those on prosthesis supported by four implants, the additional procedures added for the placement of the two additional implants do not seem to be justified.

CONCLUSION

The basic principles of biomechanics must be respected when doing oral implants (or) else the case may fail. The primer of oral implant biomechanics should familiarize the clinician with key issues to be confronted when using oral implants.

To a large extent, the biomechanical consideration for implants follows simple mechanical rules based

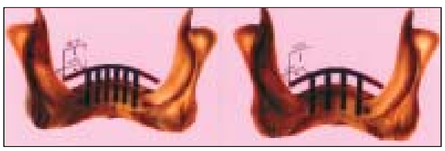

Figure 10: Illustrative photograph showing mandible with four implants and six implants between two mental foramina with their cantilever biomechanics

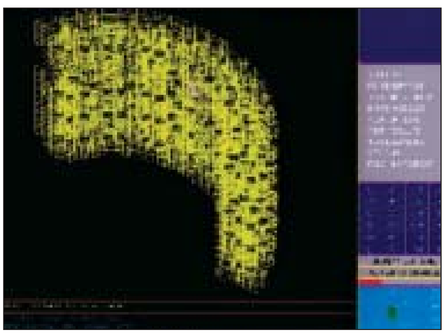

Figure 11: Finite-element model with 48176 elements and 48464 nodes of six implants placed in mandibular model

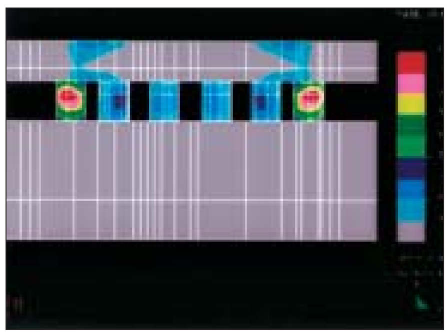

Figure 12: Finite-element stress distribution analysis of six implants supported mandibular over-denture

on the leverage principles. By considering the patient's functional behaviour, limiting the extension of the prosthesis and controlling the occlusal pattern and contacts, possible overload situations can be minimized.

REFERENCES

1. Watzek G. Biomechanics of Endosseous Implants In: Endosseous Implant- Scientific and Clinical aspects. Chicago: Quintessence Publishing Co. Inc, 1996. p. 291-317.
2. Brunski J, Block MS, Kent JN. Biomechanics of dental implants. In: Endosseous implants for maxillofacial reconstruction. Philadelphia: W.B. Saunders Co. Inc; 1995. p. 22-39.
3. Papavasiliou G, Tripodakis A, Kamposiora P, Strub JR, Bayne SC. Finite element analysis of ceramic-abutment restoration combinations for osseointegrated implants. Int J Prosthodont 1996;9:254-60.
4. Bidez MW, Misch CE. Clinical Biomechanics in Implant dentistry In: Misch CE. Contemporary Implant Dentistry. 2nd Ed. St. Louis: Mosby Inc; 1995. p. 303-16.
5. Rangert BO, Pallaci P. Optimal implant positioning and soft tissue management for the Branemark System. Chicago: Quintessence Publishing Co. Inc; 1995. p. 21-39.
6. Takayama H, Hobo S. Biomechanical consideration on Osseointegrated implants. In: Osseointegration and Occlusal Rehabilitation. Tokyo: Quintessence Publishing Co. Inc; 1989. p. 265-80.
7. Skalak R. Biomechanical consideration of Osseointegrated prosthesis. J Prosthet Dent 1983;49:843-8.
8. Bides M. Force transfers in implant dentistry- Basic concepts and principles. J Oral Implantology 1992;18:264-74.
9. Murph WM, Williams KR. Stress in the bone adjacent to dental implants. J Oral Rehabil 1995;22:897-903.
10. Papavasiliou G, Kamposiora P, Bayne SC, Felton DA. Three dimensional finite element analysis of stress distribution around single tooth implant as a function of bony support, prosthesis type and loading during function. J Prosthet Dent 1996;76:633-40.
11. Sertgoaz A, Guvener S. Finite element analysis of the effect of cantilever and implant length on stress distribution in an implant supported fixed prosthesis. J Prosthet Dent 1996;76:165-9.
12. Clleland NL, Lee JK, Bimbenet EC, Brantley WA. A three dimensional finite element stress analysis of angled abutments for an implant placed in the anterior maxilla. J Prosthodont 1995;4:95-100.
13. Canay S, Hersek N, Akipinar I, Asik Z. Comparison of stress distribution around vertical and angled implants with finite element analysis. Quintessence Int 1996;27:591-8.