EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

Vol. 68, 3659:3669, October, 2022

Print ISSN 0070-9484 • Online ISSN 2090-2360

Fixed Prosthodontics and Dental Materials

Submit Date : 04-08-2022 • Accept Date : 19-08-2022 • Available online: 01-10-2022 • DOI :10.21608/edj.2022.146338.2201

# INFLUENCE OF DIFFERENT IMPLANT ABUTMENT CONNECTION ON FATIGUE LIFE OF BONE IN EDENTULOUS HEMIMANDIBULECTOMY CASES RESTORED BY IMPLANT SUPPORTED OVERDENTURE. A FINITE ELEMENT ANALYSIS

Reem Eldien Gamal[*], Amr Mohamed Ismail Badr[**] and Emad Mohammed Agamy [***]

## ABSTRACT

**Background**: Stability of implant bone interface is a critical determinant for long term success of implant supported prostheses. This is of paramount importance in edentulous patients undergoing haememandibulectomy due to small remaining bony foundation area combined with increased level of stresses. Fatigue life of bone is affected by amount of stress transmitted which may exceed physiological tolerance of bone with subsequent resorption. Implant abutment connection system (IACS) is an influential factor affecting stress distribution. **Objective:** The purpose of the study is to compare the effect of different type of implant abutment connection system (external hexagonal, internal hexagonal and internal conical) of used implants under the overdenture in fatigue life of remaining bone of hemimandible. **Materials & methods:** A three-dimensional finite element study model was constructed and duplicated three times. The model was composed of hemimandible screwed with reconstructive plate and restored by overdenture. The overdenture was retained by three implants of the same type of (IACS) at three positions. The only difference between the three models was the type of IACS used. Model (A) had implants of external hexagonal connection system, Model (B) had implants of internal hexagonal connection and model (C) had internal conical connection. **Results:** bone of internal hexagonal connection model showed largest number of fatigue life cycles, whereas external hexagonal connection showed smallest one and the values of internal conical connection model was intermediate. **Conclusion:** under the limitations of the current study, it may be concluded that using internal hexagonal IACS in implant supported mandibular overdenture rehabilitating hemimandible may be the most suitable type

**KEYWORDS:** Finite element analysis, implant abutment connection system, bone resorption, stress distribution, fatigue life

---

* Teaching Assistant Prosthetic Dentistry Department, Faculty of Dentistry, Minia University, Egypt.
*** Associate Professor and Head of Prosthetic Dentistry Department, Faculty of Dentistry, Minia University, Egypt.
*** Professor, Prosthetic Dentistry Department, Faculty of Dentistry, Minia University, and Dean , Faculty of Dentistry Delta University, Egypt.

Article is licensed under a Creative Commons Attribution 4.0 International License

## INTRODUCTION

Prosthetic rehabilitation of edentulous hemimandible is a challengeable one due to poor remaining foundation area combined with presence of intervening stresses (1). Implant supported overdentures represent the best solution compared to traditional complete denture as it have been advocated in many literatures as a means of preserving the remaining structures and increasing denture stability, retention and support thus extending the longevity of the prostheses (2). Telescopic attachment in these cases is the most used one due to simple technical construction, economically available and providing better force distribution due to the circumferential relation of the outer crown to the abutment (3,4). Unlike natural teeth; which are surrounded by periodontal ligaments, implants have direct contact with the bone and the implant bone interface shows less resilience. As a result, they transmit occlusal loads directly to the peripheral bone (5,6). Bone resorption becomes the net results if transmitted stresses exceed the physiological equilibrium of bone remodeling (7). According to Rieger et al 1990, stresses that exceed 5 MPa range have been reported to cause bone resorption (8). Bone resorption may be at any point within jawbone and at implant bone interface and the last cause implant loosening and failure to the prostheses as whole (9). Therefore, stress distribution and amount of load transferred to implant bone interface have a very influential effect on implant success or failure (10). This interface must tolerate occlusal stresses without adverse tissue response (11). And the occlusal stresses should be functionally distributed m to peri implant bone interface at physiological level (12).

Implant Abutment Connection System (IACS) plays the crucial role in maintaining the biomechanical criteria of the implant. Design configuration of IACS determines the pattern of stress distribution and amount of stresses transmitted to bone and all prosthetic components (13). Since IACS determines amount of stresses transmitted to implant itself, to bone-implant interface and to implant-abutment interface, it influence the performance and maintenance of bone, implant integrity, osseointegration and implant supported prostheses (14-19).

The strength of IACS determines whether it can withstand the occlusal loads or not. On the other hand, the rigidity of the IACS aims to minimize any micromovements within prosthetic components(20). Decreasing micromovement associated with uniform load transfer finally aid in elimination of microgap formation and microbial leakage thus preventing peri implantitis and bone loss (21). During functional loading on the overdenture, forces are transmitted to implant via the attachment and then generation of stresses are created within IACS(22,23). Some stresses are dissipated to the IACS, and the remaining are redistributed to implant itself, bone-implant interface and implant- abutment interface(22). Many design characteristics within IACS interface make one IACS differ from the other regarding width of mating surface area, position of this mating, depth of the mating inside the fixed implant body, presence of platform switching, antirational features and retaining methods as screw or frictional fit connection

The great loss of foundation area due to hemimandibulectomy makes bone more sensitive to stresses than in normal situation (1). Moreover, presence of many intervening stresses in such cases makes implants subjected to biomechanical risk (24). The goal of treatment is to preserve bone as historically crestal bone level around implants has been used as a sign of success (25). Thus, in this situations where it is not possible to perform bone grafting for the resected side or increasing implants number, the alternative approach may involve using the most suitable connection type from biomechanical point of view (26).

Although many case reports have been made for the prosthetic treatment of hemimandibulectomy patients, very few studies have investigated using implants with different attachments and IACS (1).

## AIM

The aim of the current study is to compare between the effect of three types of implant abutment connection system (IACS) on stress distribution pattern and fatigue life of bone in edentulous haemimandible restored by implant supported overdenture under simulated physiological factors and loading condition

## MATERIALS AND METHODS

A 3D digital model simulating an edentulous hemimandible was created. The model featured a resection from midline, and a reconstruction plate with prosthetic condyle was modeled and attached to the intact half of the mandible at midline using plate and four screws. The model simulated also an implant supported overdenture retained by three parallel walled telescopic crown attachments over three implants

Two models were duplicated from the original model to obtain 3 models. The only difference between them was the type of implant abutment connection system (IACS) of the used implants, each model had 3 implants of one type

The first model had 3 implants of Conventional external hexagonal connection, the second model had 3 implants of Internal hexagonal connection and the third model had three implants of Internal conical connection.

The digital model was created from scanning of natural mandible and scanning of artificial teeth by Identica hybrid 3D dental scanner[*]. Identica hybrid accuracy was documented according to ISO 12836 industry international standard which provide optimal results.

**The following steps were carried out:**

1. Selecting the analytical model.
2. Scanning of the mandibular edentulous ridge.
3. Editing and preparing the model.4. Three dimensional drawing of model components.
4. Combining and subtraction of all components.
5. Assembling of the three dimensional components.
6. Transferring the data to Ansys software program
7. Defining the material properties for each component.
8. Defining contacts and gaps between components.
9. Defining model fixture and restrain for each model.
10. Defining loads applied on each model.
11. Meshing the models.
12. Running the analysis.
13. Collection of the results

### 1. Selecting the analytical model

A dried edentulous human mandible was selected. The mandible had no developmental abnormalities or gross defect.

### 2. Scanning of the mandibular edentulous ridge

An Identica hybrid 3D dental scanner was used to scan the mandible and produced STL file for the mandible.

The scanner produced the outer surface of the mandible (compact bone) and artificial teeth of denture whereas solid work software program 2017 was used to draw the cancellous bone, mucosa and denture base.

### 3. Editing and preparing the model

The STL file produced from Identica hybrid 3D dental scanner was converted to a solid work model by the Solidworks software program

---

[*] MEDIT corp. Seongbuk-gu, Seoul, Korea.

## 4. Three-dimensional drawing of the model components

The mandible was drawn directly by the solid works program using STL file produced from Identica hybrid 3D dental scanner. Drawing of bone, mucosa, implants and overdenture was similar to previous study of Mohsen H in 2016 (27) with the following exceptions

After drawing of the compact and cancellous bone of the mandible, simulation of the mandibular resection and reconstruction plates was carried as follows

### *4.1. Longitudinal cutting of mandibular model at midline*

Longitudinal cutting at midline is done to simulate hemimandibulectomy and separate the mandibular model into right and left sides

### *4.2. Drawing the reconstruction plate*

The left mandibular half was kept intact and the right one was minimized to simulate the reconstruction plate. Minimization was done in all direction keeping the anteroposterior length of the mandibular body and vertical height of the ramus intact. The miniature result of the mandibular half was used to simulate the reconstruction plate with semi oval cross section of 12 mm height and 5.5 mm thickness. The superior end of reconstructive plate vertical plane has rounded cross section with 7mm diameter representing the prosthetic condyle.

### *4.3. Drawing a small connecting plate with four screws*

A rectangle with 15.7 mm length and 8.5 mm width was drawn with four screws penetrating the bony half each of 4.5 mm length and 3 mm diameter, this rectangle was a simulated extension from the reconstruction plate to the native side of the mandible.

### *4.4 Drawing the artificial teeth*

The same scanner (Identica hybrid 3D dental scanner) was used to scan the artificial teeth and the move and copy properties of the software were used to set the scanned teeth over the denture base.

### *4.5. Modification of artificial teeth*

Modification was done to occlusal surfaces to make it semi flat by decreasing the height of cusps and raising the depression of grooves, semi anatomical teeth were used to decrease dislodging forces acting on denture.

### *4.6. Model duplication*

The final model was duplicated two times to create 3 identical three-dimensional models of hemimandible with reconstruction plate restored by overdenture ready for implant insertion.

### *4.7. Drawing the implants*

Three identical types of implants, that differ from one another in IACS were drawn. In this study, the Winsix implant system which produced by American biosafin Company was the reference in the drawing. Winsix implant system was chosen as it manufactures the three types. Presence of one manufacturer ensure standardization of other factors and allow implant abutment connection system (IACS) to be the only variable factor so results will accurately demonstrate the effect of it

The implant body for all (IACS) was standardized; length(13mm), diameter (4.5mm) and identical body threads. Parallel walled abutment(5mm) and abutment fixation screw were also standardized.

### *4.8.a. Implant with external hexagonal IACS*

Implant is named TTX in the catalogue. Following Winsix catalogue, implants were drawn with external hexagonal connection with 0.7 mm length and 2.4 width is drawn external to implant body

### *4.8.b. Implant with internal hexagonal IACS*

Implant is named TTI in the catalogue. Following Winsix catalogue, implants were drawn with 1.7 mm internal hexagonal connection depressed internally to implant body.

### *4.8.c. Implant with internal conical IACS*

Implant is named TTC in the catalogue. Following Winsix catalogue, implants were drawn with 3mm longitudinal length of a conical connection with 3-degree conicity. A 1.5 mm internal hexagonal connection apical to conical connection

### *4.9. Drawing the telescopic attachment system*

Telescopic attachment system composed of both primary and secondary crowns was used. The primary telescope was the implant abutment and the secondary crown is drawn with 5.5 mm diameter and 6 mm length following winsix implant catalogue

### *4.10. Implant insertion and models identification*

Each of the three identical 3D models of hemimandible was supplied by one type of the drawn implants at identical sites. Thus the only difference between the three models is the IACS

Model A: 3 implants of TTX type

Model B: 3 implants of TTI type

Model C: 3 implants of TTC type

The three implants were inserted at first molar, canine and central incisors region of intact side using the denture as a reference and are numbered implant 1, implant 2 and implant 3 respectively

## 5. Subtractions of all components:

### *5.1. Subtractions of components*

All components of this model were subtracted from each other leaving one component with reference points by which assembly could be done. This step was repeated for each component in each model independently.

### *5.2. Combining of mirror components*

All components which are in contact with their mirror structures were given the same property and were combined to each other and defined a specific contact type e.g.: mucosa and denture base (slippage non penetrating contact) , the artificial teeth and the denture base ( bonded contact) etc .

## 6. Assembling of the three dimensional components:

The constructed components were assembled to form the model with the telescopic attachment and the overdenture prosthesis. The technique of model assembly was done by the mating function of the assembly mode in solid work program software. The mating function creates one or more geometrical relationship between different components that facilitates the assembling process.

## 7. Transferring the data to Ansys software program

The three 3D assembled models were transferred to Ansys 14.5 software. This software has superior accuracy in meshing and running the analysis than Solid works software.

## 8. Defining the material properties for each component:

All materials in the study were considered to be homogenous, isotropic and linearly elastic. The modulus of elasticity and Poisson’s ratio for the different component materials used in the study are listed in (Table 1).

## 9. Defining contacts and gabs between components

All components were constructed in a way that assured 100% contacts along every interface i.e. there were no gaps or interfaces.

*-Two types of contacts were defined:*

a- Bonded contact between the two contacting surfaces along the interface; which means that

TABLE (1) Material properties

| Material/ Components | Elastic modulus ''Mpa'' | Poisson's ratio | Reference |
|---|---|---|---|
| Acrylic Resin of denture base and artificial teeth | 2700 | 0.35 | (Gultekin et al., 2012) |
| Compact Bone | 14000 | 0.3 | (Chun et al., 2005) (Amer et al ,2015) |
| Spongy bone | 3000 | 0.3 | (Mehreli et al., 2013) |
| Soft tissue / Mucosa | 10 | 0.4 | (Gultekin et al., 2012) |
| Ti-6Al-4V/ Implants | 107200 | 0.30 | (Álvarez-Arenal et al., 2014) |
| Stainless steel type 304 in telescopic attachment | 13200 | 0.29 | (Álvarez-Arenal et al., 2014) (Gultekin et al., 2012) |

these objects are displaced as one unit upon load application and that the two contacting bodies cannot be separated nor penetrated.

b- Slip (no penetration) contact between the two contacting surfaces along the interface; which allows some degree of movements between them. All the interfaces between the surfaces were defined as bonded contact except the structures presented in (Table 2)

TABLE (2) Structures with slip contact

| |
|---|
| Denture and Implant |
| Denture and mucosa |
| Implant abutment and secondary crown of the telescopic attachment system |

### 10. Defining fixture and restraint for each model:

The restraint property is a special feature in stress analysis programs that allows restriction of displacements on vertices, edges, or faces for use during static analysis of the model.

As a solid mesh was planned; the resultant nodes were allowed to translate along any of the 3 orthogonal directions unless a restraint was applied, but no rotation was allowed.

The restraints applied were fixed restraint on the prosthetic condyle, bottom surface and condylar area of the intact side i.e. no translation was allowed for these surfaces in all directions.

### 11. Defining loads applied on each model

In such situation, due to muscle defect of the resected side, patient prefer to function only on intact side (1) so unilateral force application is applied over posterior teeth of the mandibular intact side. As the masticatory force is a multidirectional force, the applied force is directional in axial, buccolingual and mesiodistal directions in the same time.(28)

The force is also applicated over posterior teeth (teeth No 5,6,7) in the area of central groove, following lingualized occlusion concept which is followed in such cases to decrease displacement.

Masticatory forces have a wide range varying from 50 N to 2440 N (29). A magnitude of 450 N was chosen which won't be considered high as patient in such cases feel a great functional insufficiency and try to exert more force to function well.

### 12. Meshing the models:

Meshing is the process of subdividing the geometric model into small pieces called elements connected at common points called nodes.

A solid tetrahedral patch conforming mesh was used, the resultant nodes were allowed to translate along any of the 3 orthogonal directions unless a restraint was applied, but no rotation was allowed.

## 13. Running of the tests:

The analysis was run by mechanical APDL solver in Ansys 14.5 software which is an iterative method which solve the equations using approximate techniques; where in each iteration a solution is assumed and the associated errors are evaluated. By introducing the SN curve for each material, number of cycles before failure could be calculated

## 14. Collection of the results

The results were presented as Von Misses stress that was calculated at the elements in Mega Pascal (Mpa). Calculation is done for the average stresses, the minimum stresses and the maximum stresses values for implants, compact bone, spongy bone and implant bone interfaces around each implant in all the three models. Fatigue analysis for bone is represented by number of cycles.

## RESULTS

Table 3 shows the maximum stresses obtained for the different components of the three models.

### Fatigue results

Fatigue results are represented by number of cycles before material fail. Fatigue analysis for all areas of hemimandible compact bone is done for the three models.

The results showing that bone in model B has the largest number of fatigue life cycles which predict longer life in performance, whereas bone of model A show smallest one and cycles number of bone in model C was intermediate. Results of compact bone fatigue life cycles in the three models are presented in Table 4 and figures 1-3

TABLE (3) Stress distribution in models components

| Components | Model A TTX implants | Model B TTI implants | Model C TTC implants |
|---|---|---|---|
| Compact bone | 15 MPa | 10.8 MPa | 13.65 MPa |
| Spongy bone | 4.5MPa | 0.85 MPa | 3.4 MPa |
| Implant 1 bone interface | 15MPa | 6 MPa | 9.7MPa |
| Implant 2 bone interface | 5.5 MPa | 4.9 MPa | 5 MPa |
| Implant 3 bone interface | 5 MPa | 2.9 | 3.7 MPa |
| Implant No 1 | 11.7 MPa | 11.5 MPa | 13.4 MPa |
| Implant No 2 | 12.9 MPa | 14 MPa | 13.9 MPa |
| Implant No 3 | 14.8 MPa | 19.2 MPa | 18.5 MPa |

TABLE (4) Compact bone fatigue analysis

| Components | Model A TTX implants | Model B TTI implants | Model C TTC implants |
|---|---|---|---|
| Fatigue life cycles | 1.286e +006 cycles | 1.747e +006 cycles | 1.422e +006 cycles |

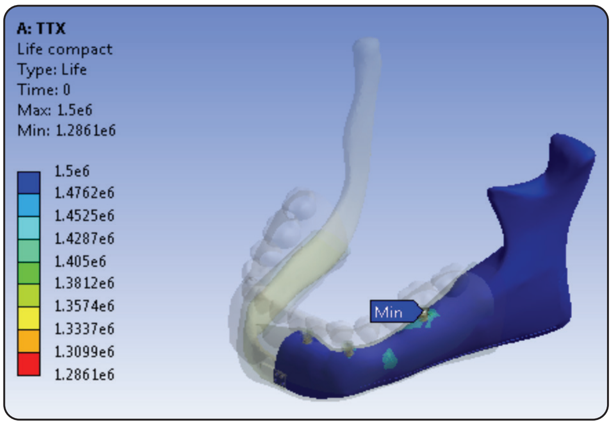

Fig. (1) Fatigue life of compact bone in the model with external IACS

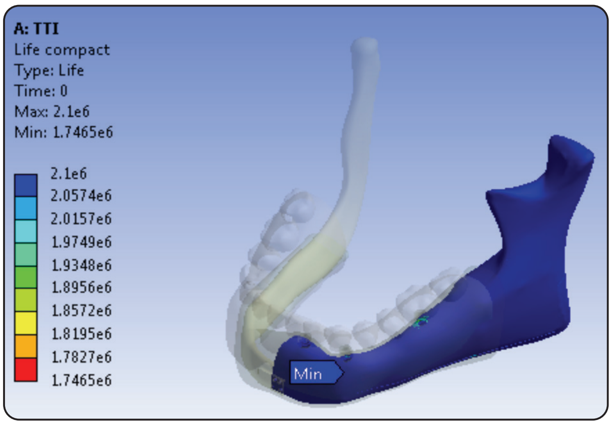

Fig. (2) Fatigue life of compact bone in the model with internal IACS

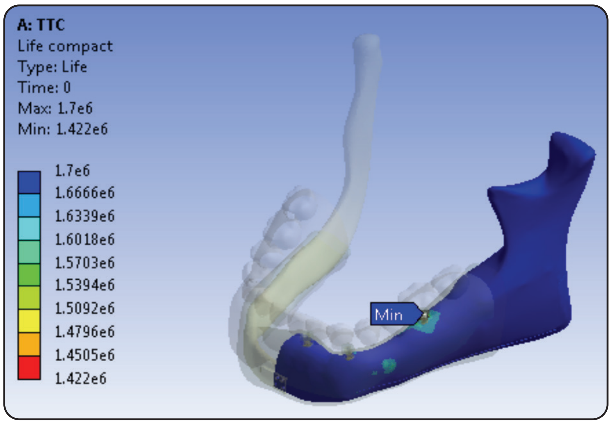

Fig. (3) Fatigue life of compact bone in the model with conical IACS

## DISCUSSION

Finite element analysis FEA has been used extensively to predict the biomechanical performance of the jawbone and interface areas with implants (30,31). Dynamic loads (32) in the form of repeated cycles of force application have been used to evaluate fatigue life of bone by calculating number of cyclic loads the material can withstand before failure. No previous studies about finite element stress analysis in hemimandibulectomy cases could be found in the literature. These cases are in need to be restored with dental implants to support the prosthetic appliances provided. In these cases, implants will have superior biomechanical behavior regarding stresses distribution in order to preserve the remaining bone and maintain success of the prostheses (1). Research should evaluate the effect of using different implants in fatigue life of bone and consequentially clinical choosing of the most suitable implant in treatment planning for such cases. Many researchers considered IACS as the most important factor between different implant types that guide the biomechanical behavior of them (33). That is why the current study selected to explore the effect of using the three IACS types in hemimandibulectomy for evaluation (TTX, TTI, TTC).

The results of the static analysis show that the highest values of von mises stresses in compact bone are found in model A while the lowest value was in model B and model C has an intermediate one which in agreement with literature findings of Tang et al 2012 (33). Further support for these findings is the results of another research which concluded that internal hexagonal abutment produces the lowest stress value in bone followed by internal conical and external hexagonal connection respectively (35).

To understand these results, the effect of many design characteristics of IACS interface should be understood. The superior biomechanical behavior of TTI is due to the wide contact area of IACS interface area regarding length and width combined with the internal position of the interface inside implant which ensure great engagement and securing of the abutment providing a stable joint able to centralize the stresses along implant body and decrease stresses reached to bone. On the other hand, the unfavorable behavior of the TTx is due to narrow and short contact area of IACS interface which lead to weak unstable joint can’t centralize the stresses along implant body, especially under oblique loading. And the most generated stresses were taken at the compact bone around implant neck adjacent to first microthreads of the implant due to close contact of this area with bone tissue (26,35).

Internal cone connection is a modified type of true morse taper. TTC implant has a hexagonal connection at the apical area of the cone connection and retaining screw. This modification is done to overcome morse taper problems regarding the possibility of repetition and lack of index feature. Unfortunately, this modification mis characterize the great stability of morse taper connection (37). Tang in 2012 found that stress concentration at the end of the internal tapered connection where the abutment hex goes deep into the implant. This feature alters the stress distribution in bone (33). Yet this cannot explain the intermediate values in the current study; however, his model configuration was different and testing only single crowns. The effect of full denture and mandibular resection cannot be overlocked. This may have contributed to the results of the current study.

The values of von mises stresses induced in spongy bone in the three models show the same order in those stresses of cortical bone. This is a normal finding, as stresses induced by occlusal load are initially transferred from implant to cortical bone and a small amount of remaining stresses spreads to spongy bone. Higher stress values are observed in cortical bone because of higher modulus of elasticity and bone density compared to spongy bone (37).

Von mises stresses value of implant bone interface around implant No1 is higher than that of implant No 2 and No 3 respectively in the three models. implant site No1 is nearer to the applied stresses than other two implants which explains the higher values recorded. It indicates also that greater load is shared to this area and maybe it would have been better to use two adjacent implants at this site. The other sites are away from force application area, and they are near each other which may indicate some load sharing.

On the other hand, terminal implant (No 3); which is inserted near the defect, show the highest von mises stress values in all models followed by implant No 2 then No 1. Terminal implants in all models receive many components of force weather axial, horizontal or rotational, this does not occur in other implants No 1 or 2 because of the unilateral force application due to muscle incoordination inducing the patient to functioning in only the intact mandibular side where implants were inserted (38). Arrangement of implants in only one side under the denture whether due to financial reason or lack of bone in the other side creates a cantilever effect with bending moments and subsequent mechanical overload within terminal implants (1).

Fatigue results show that bone of TTI model exhibit the maximum number of fatigue life cycles whereas bone of TTX model has the lowest number of cycles and bone of TTC models has intermediate number between TTI and TTX. This result predicts longer life of bone before failure (resorption) using TTI implant followed by TTC and TTX respectively. However, it should be remembered that these results are valid for the test condition only. In real life bone undergoes deposition process in response to low magnitude stresses, which increases its modulus of elasticity and will change the strain behavior.

Many health educators calculate the average numbers of bite in adult person to be 10-100 bites. On the other hand, when normal person chew, he need about 32 strokes to break down this bite and swallow it whereas in complete denture patients number of strokes per bite increase to reach 69 one. Fortunately, construction of overdenture supported by implants make patient need only 40 strokes to deal with one bite which is a great advantage (39).

Using the previous data the number of daily chewing cycles may be calculated to be 50 × 40 = 2000. If we theoretically calculate life time of models we will subdivide number of life cycles by average number of chewing cycles per day.

Model A = 1.286e+006 ÷ 2000 = 643 days = about 1,76 year

Model B= 1.747e+006 ÷ 2000 = 873.5 days = about 2.4 year

Model C= 1.422e+006 ÷ 2000 = 711 days = about 1.95 year

This should again be interpreted cautiously as remodeling process will change bone parameters and the tested loading condition is actually very high for such patients.

## CONCLUSION

Under the limitations of the current study, it may be concluded that using internal hexagonal IACS in implant supported mandibular overdenture rehabilitating hemimandible may be the most suitable type.

## REFERENCES

1. Ali S, Zakaria M, Baroudi K. Stress analysis of two attachment types for implant supported overdenture in hemimandibulectomy cases.EC Dental science.2016;5.5:1174-1181.
2. Rownaq M, Nag D, Sankar V. Comparison of stress induced in mandible around an implant supported overdenture with locator and telescopic crowns – a finite element analysis. Medicine and pharmacy reports. 2020; 93:181-189.
3. Zou D, Wu Y, Huang W, Wang F, Wang S, Zhang Z, et al. A 3-year prospective clinical study of telescopic crown, bar, and locator attachments for removable four implant–supported maxillary overdentures. Int J Prosthodont. 2013; 26:566-573.
4. Oh JR, Woo YH, Lee SB, Bak J. Finite element analysis of stress distribution on telescopic system for mandibular implant supported overdenture. J Korean Acad Prosthodont. 2008; 46:359-371.
5. Ishigaki S, Nakano T, Yamada S, Nakamura T, Takashima F. Biomechanical stress in bone surrounding an implantunder simulated chewing, Clin. Oral Implants Res.2003;14: 97-102.
6. Pesqueira AA, Goiato MC, Filho HG, Monteiro DR, dos Santos DM, Haddad MF et al. Use of stress analysis methods to evaluate the biomechanics of oral rehabilitation with implants. J. Oral Implantol.2014;40: 217-228.
7. Villa G, Salles B, Jose W. Prosthetic abutment influences bone biomechanical behavior of immediately loaded implants. Braz. Oral Res. 2016; 30:1-9.
8. Kang X, Li Y, Wang Y. Relationships of stresses on alveolar bone and abutment from various bite forces by three-dimensional finite element analysis. Biomed research international. 2020; 10:1-9.
9. Jae chun H, Shin H, Hyun C. Influence of implant abutment type on stress distribution in bone under various loading condition using finite element analysis. Int J ORAL Maxillofac Implants.2006;21:195-202.
10. C.E.E. Rezende, M. Chase-Diaz, M.D. Costa, M.L. Albarracin, G. Paschoeto, E.A.C. Sousa et al., Stress distribution in single dental implant system: Three-dimensional finite element analysis based on an in vitro experimental model, J.Craniofac. Surg. 2015; 26: 2196-2200.
11. C ehreli MC, Duyk J, De Cooman M, Puers R, Naert I. Implant design and interface force transfer. A photoelastic and strain-gauge analysis. Clin Oral Impl Res. 2004; 15:249–257.
12. Anami L, Piero M, Antonio M. Application of Finite Element Analysis in Implant Dentistry.2015;2:155-162
13. Saidin S, Rafiq M, Suliman E. Effects of different implant–abutment connections on micromotion and stress distribution: Prediction of microgap formation. J of Dentistry. 2012;40:467-474.
14. E.O. Almeida, E.P. Rocha, A.C. Freitas-Junior, R.B. Anchieta, R. Poveda, N. Gupta et al., Tilted and short implants supporting fixed prosthesis in an atrophic maxilla: A 3D-FEA biomechanical evaluation, Clin. Implant Dent. Relat. Res. 2015;17:332-342.
15. L. Minatel, F.R. Verri, G.A.H. Kudo, D.A. de Faria Almeida, V.E. de Souza Batista, C.A.A. Lemos and E.P. Pellizzer. Effect of different types of prosthetic platforms on stress-distribution in dental implant-supported prostheses, Mater. Sci.Eng. 2017;71:35-42.
16. J.M.F.K. Takahashi, A.C. Dayrell, R.L.X. Consani, M.A. de Arruda Nobilo, G.E.P. Henriques and M.F. Mesquita, Stress evaluation of implant-abutment connections under different loading conditions: A 3D finite element study, J. Oral Implantol. 2015;41:133-137.
17. E. Borie, I.A. Orsi, P.Y. Noritomi and D.T. Kemmoku, Three-dimensional finite element analysis of the biomechanical behaviors of implants with different connections, lengths, and diameters placed in the maxillary anterior region, Int. J.Oral Maxillofac. Implants. 2016;31:101-110.
18. D.A. de Faria Almeida, E.P. Pellizzer, F.R. Verri, J.F. Santiago Jr and P.S.P. de Carvalho, Influence of tapered and external hexagon connections on bone stresses around tilted dental implants: Three-dimensional finite element methodwith statistical analysis, J. Periodontol. 2014;85: 261-269.

19. M.A. Carvalho, B.S. Sotto-Maior, A.A.D.B. Cury and G.E.P. Henriques, Effect of platform connection and abutment material on stress distribution in single anterior implant-supported restorations: A nonlinear 3-dimensional finite element analysis, J. Prosthet. Dent. 2014;112:1096-1102

20. Devarago K, Sangana J, Koshy J, Kumara S. Comparison of biomechanical properities of different implant abutment connections. Indian journal of dental science. 2019;10:180-183

21. Segundo RM, Oshima HM, da Silva IN, Burnett Jr LH, Mota EG, Silva LL. Stress distribution of an internal connection implant prostheses set: a 3D finite element analysis. Stomatologija Baltic Dental and Maxillofacial Journal 2009;11:55–9.

22. Sendyk C, Wilson R, Sergio E, Patriccia R and Quaresma S. Afinite element analysis of two different dental implants: stress distribution in the prosthesis, abutment, implant and supporting bone. J. of oral implantology. 2008;34:1-6

23. Nell M, Johnson N, Chaya loo Y, Guan H and Van staden R. Comparative analysis of internal and external hex crown connection system- a finite element study. J. Biological science and Engineering. 2008;1:10-14

24. Antoninha A, Cardoso,P, Jose W, Salles W and Camargos G. Prosthetic abutment influences bone biomechanical behavior of immediately loaded implants. Braz. Oral Res. 2016;30:1-9.

25. Cochran D and Sasada Y. Implant abutment connection: A review of biological consequence and peri-implantitis implications. INT J Oral Maxillofac Implants. 2017;32:1296-1307.

26. Piza E, Marcela J, Aparecido C, Augusto D, Ferreira J, Ramos F and Lucia S. Three- Dimensional finite element analysis of varying diameter and connection type in implants with high crown-implant ratio.Braz Dent J.2018;29:36-42.

27. Mohsen H. Effect of changing implant position in single implant supported mandibular overdenture, 3D finite element study. Msc Thesis, Faculty of Dentistry, Minia university. 2016:27-50.

28. U.R.Patil, P.N.Dhatrak and B.M.Shinde. Fatigue life of dental implant- A review. IOSRJMCE. 2016;5:1-5

29. Keskin H, Ozdemir M and Balik A. Effect of different abutment connection design on the stress distribution around five different implants: A 3- dimensional finite element analysis. J Oral Implanto. 2012;38:491-496.

30. Patra A, Detolla D, Andreana S, Buhite R and Comella B. The role of the finite element model in dental implants. J Oral Implanto. 2000;26(2):77-81.

31. Liu G.R, Tan K.B and Geng J.P. Application of finite element analysis in implant dentistry: A review of the literature. J Prosthet Dent 2001;85:98-585.

32. Steinebrunner L, Wolfart S, Bo¨bmann K and Kern M. In vitro evaluation of bacterial leakage along the implant–abutment interface of different implant systems. International Journal of Oral & Maxillofacial Implants 2005;20:875-81.

33. Tang CB, Liu SY, Zhou GX, Yu JH, Zhang GD, Bao YD, Wang QJ. Nonlinear finite element analysis of three implant–abutment interface designs. Int J Oral Sci 4, 101–108 (2012). https://doi.org/10.1038/ijos.2012.35

34. Abu Kasim N.H, Suliman E, Rafiq M and Saddin S. Effect of different implant-abutment connections on micromotion and stress distribution: prediction of microgap formation. Journal of dentistry. 2012;40:467-474.

35. Faria Almeida DA, Pellizzer EP, Verri FR, Santiago Jr JF and Carvalho PS. Influence of tapered and external hexagon connections on bone stresses around tilted dental implants:Three-dimensional finite element method with statistical analysis. J Periodontol 2014;85:261-269.

36. Antonio M, Yoshito P, Piero M, Eidi F, Magalhaes J and Costa L. Stress distribution around osseointegrated implants with different internal-cone connections:photoelastic and finite element analysis. J Oral Implanto. 2015; 41(2):155-162.

37. Hussain A, Shenoy K.K, Paulose A and Sarfaraz H. A three dimensional finite element analysis of a passive and frictional fit implant abutment interface and the influence of occlusal table dimension on the stress distribution pattern on the implant and surrounding bone. J Indian Prosthodont Soc. 2015;15(3):229-236.

38. Beumer J, Marunick MT, Curtis TA and Roumanas E. Acquired defects of the mandible: etiology, treahment, and rehabilitation. Maxillofacial rehabilitatuon: ptosthodontic and surgical consideratuons. 2006;28(1):22-33.

39. Jawhar A, Nagrath R, Lahori M. A compatative evaluation of scewing efficiency, masticatory bite force and patient satisfaction between conventional denture and implant supported mandibular overdenture: An in vivo study. The journal of indian prosthodontic society.2017; 17:361-372.