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EVALUATION OF STRESSES DISTRIBUTION PATTERN IN IMPLANT- RETAINED MAXILLARY OBTURATORS USING NOVA-LOCK, BALL & LOCATOR-BAR ATTACHMENT SYSTEMS. (THREE DIMENSIONAL FINITE ELEMENT ANALYSIS)

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ABSTRACT

Purpose: This study was an in in-vitro study conducted to compare the stress distribution pattern in implant retained maxillary obturators with three different attachment systems with the aid of three dimensional finite element analysis.

Methods: CT scan was made for a patient with hemi-maxillectomy defect. The CT scan file was exported to a personal computer with Materialize Mimics 10.01 program (Materialize, interactive medical image (***Materialize Leuven, Belgium)***. Mimics were utilized to modify the CT scan of the maxilla to construct 3-D model with Solid Works, Concord, Massachusetts, USA) for finite element stress analysis. All components of the models were constructed thereafter, superimposed till construction of maxillary obturator models. Three implants were inserted in the alveolar bone on the intact side. Ball & Nova-lock locator/ bar attachment systems were simulated according to their structural configurations. A static load of 100 N load was applied vertically & obliquely on the defect side. ANSYS program (Canonsburg, PA, USA) was utilized to solve the problems, The resultant Von Misses stresses in bone surrounding implants were evaluated and compared in the 3 studied models.

Results: The highest Von Misses stresses were found in cortical bony layers around the implant adjacent to defect & the least stresses at the area of 3rd implant. Nova-lock retained implant obturtors had recorded the least Von Misses stresses (20. 479 &21.675 Mpa) in comparison to Ball (40.762 & 41.488 Mpa) & locator bar attachment systems (43.526 & 47.203 Mpa) under vertical & oblique load application respectively. All models had shown the highest stresses on oblique load application on the defect side.

Conclusions: Within the limitations of this study various conclusions could be drawn:

- The load direction has more important role than the attachment type in stress distribution pattern in implant retained maxillary obturators.
- Nova- lock attachment system may induce the least stresses onto implant/ bone interface followed by Ball & locator bar attachment systems.
- The Locator/ bar attachment may allow better stress distribution in implant retained maxillary obturators than other Bar systems.

KEYWORDS: **Maxillary , Obturators, implants, attachments, stresses, FEA.**

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INTRODUCTION

Patients with maxillary defects due to surgical tumor resection mostly suffer from physical and psychological trauma. [1]

Rehabilitation of maxillectomy patients is considered a real challenge for patients and prosthodontists. Prosthetic obturator is an effective means to close the defect, separate the oral cavity from nasal cavities, improve the speech hyper-nasality, prevent the nasal regurgitation of food and liquids, and support the facial profile.[2]

Consequently, good obtuator may improve the patient's quality of life. [3]

Rehabilitation of completely edentulous maxillectomy patients with prosthetic obturator may be considered a real problem. As the obtuarator retention , stability & support are compromised due to diminished maxillary bone after tumor resection.

The possible obturator movements present another problem; these movements depend on the amount and contour of the remaining palatal bone, the residual alveolar ridge, the defect size, and the presence of useful undercuts [4]

The problem of obturator retention may affect the treatment outcome & affect the patient's quality of life. [5,6].

Osseointegrated dental implants had provided dramatic effect on the oburator retention , support and stability for completely edentulous maxillectomy patients.

The patient's masticatory efficiency, the adaptability to the obturator and the speech intelligibility are greately improved with implant retained obturator. [7]

It was reported that the implant survival rate is 96 % or more.[8] Dental implants may be used in the defect and non-defect sides of the maxillary arch.[9]

The implant number and location may be controlled by the defect size & the remaining bone. The residual premaxillary segment remains the most ideal location for implant placement. This site is preferred as it is opposite to the most retentive portion of the defect located along the posterior lateral wall.

Moreover, most of the patients have sufficient bone quantity & density in the area of pre-maxilla.[10]

Stud & bar attachments were utilized to enhance the implant retained obturator retention & stability. O-ring and ERA attachments were preferred due to their reduced vertical height. [11]

Bar attachment had been used to splint implants in implant retained maxillary obturators for completely edentulous maxilla. It was concluded that maxillary obturator retained by milled bar had improved the obturator retention. No complication had been reported during the follow-up periods [12]

Bar-locator Attachment System may be useful for rehabilitation of completely edentulous patients. [15] As it provide better retention& stability than solitary attachments [16].

The FEA has become an increasingly useful tool to predict the effects of stress on the implant and surrounding bone [13, 14]. Vertical and transverse loads resulting from mastication may induce axial stresses and bending moments that result in stress gradients in the implant & bone. Due to the extremely complex geometry of the multiple-components in implant/abutment /bone system; FEA has been considered the most suitable tool to study the stresses affecting dental implants from the biomechanical point of view [17].

This will aid the prosthodontist to optimize the implant design & implant placement into bone; it will help to minimize stresses by proper design of the final prostheses [18] Many investigators evaluated the use of different types of attachment used with implant supported overdenture. [19,20].

This study was made to compare the stress distribution patterns in implant retained maxillary obturators using Ball, Nova-lock & Locator/ bar attachment systems with the aid of three dimensional finite element analysis.

METHODOLOGY

The following components were simulated using ANSYS program: The edentulous maxillary arch with hemi-maxillectomy defect, Bone surrounding the implants, Mucosa covering the residual ridge and palatal bone, obturator Denture base, Artificial denture teeth, dental-Implants, ball attachments, nova-lock attachments, locator –bar.

Modeling of The Maxillary Arch:

CT scanning was made for a 65-year-old female completely edentulous patient with hemi-maxillectomy defect using Asti eon 4 multi slice CT scanner with 0 - 3-mm serial axial sections. The file of the CT was then exported to the personal computer having Materialize Mimics 10.01 program (Materialize, interactive medical image control system, (***Materialize Leuven, Belgium).***

Mimics Soft- ware package was utilized to view the maxillary arch curvature , modify the CT scan of the maxilla and obtaining multiple cross sections of maxillary arch in order to form the 3-dimensional model with solid works 2018 software (Solid Works Corporation, Concord, Massachusetts, USA) for finite element stress analysis.

The maxilla was represented as a combination of cortical and cancellous bone, the bone width at the implant locations was measured and the length of bone was measured from the crest of the ridge to the floor of maxillary sinus and nasal cavity to determine the diameter and length of implant used.

Modeling of Implants & Attachments:

Implant Direct LLC, USA, Canada) measuring 3.7 × 11.5 mm in dimension, with 3.5 mm diameter platform and internal connections were used. The implant was modeled using the appropriate dimensions as given by the manufacturer. At least 1 mm bone around the neck of implant was maintained and 1 mm between the implant end and the maxillary sinus floor. The measurements of both the cortical and cancellous bone were recorded using the Mimics software and transferred as STL file to ***Geomagic Design X***, to make the reverse engineering by converting cloud of points to solid bodies, then as a final stage the solid bodies of each component of each model were imported to Solid works 2018 for the assembling procedures, superimposition and Boolean subtraction to avoid any interference different components of the geometric models. Fig. (1- a,b,c)

Three types of attachments were used (Ball abutment with collar height 1.6 mm, Zimmer dental, USA, Nova lock attachment, Straumann institute, Basel ,Switzerland Locator/bar attachment system, Zest anchor).

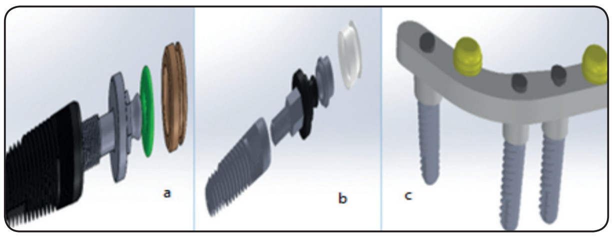

Fig. (1) (1a, b& C): Geometric models of Ball, Nova-lock, Locator/ Bar attachment Systems

Modeling of The Obturator:

The positions of the teeth were determined according to the average teeth width. ***Fig. (2)*** A cut section was made at each tooth site wherever the cortical and cancellous bony layers of bone surrounding each tooth was identified with the "Reslicing "feature in the Mimics software. The measurements of the artificial teeth used were recorded and transferred as STL file to Geomagic Design X and Reverse engineering was made corresponding to the anatomy of the teeth as cusp tips, mesial and distal marginal ridges and contact areas.

The Denture Base:

Denture Base was designed using ***Exocad software*** to fit onto the mucosa and bone side and then transferred as STL file to Geomagic Design X, to proceed with the reverse engineering phase. (Fig.2b)

After Reverse engineering phase; all models of the components were transferred to Solid works for the assembling procedures, super-imposition and Boolean subtraction to avoid any interference between bodies. The obturator at the defect side was made hollow as shown in (Fig. 2-c). Again, three holes were engraved into the fitting surface of the denture giving room for the implants & corresponding attachments. (Fig.2-d) by the ***Boolean subtraction*** operation.

Three implants were inserted in the areas directly adjacent to the defect, in the canine-premolar area & one posterior as recommended by ***Haung ,2007***)[21]

All the components of the models were assembled together using the "***mating***" feature. The bone, mucosa, implants, denture base and the different attachment systems were assembled building- up three models.

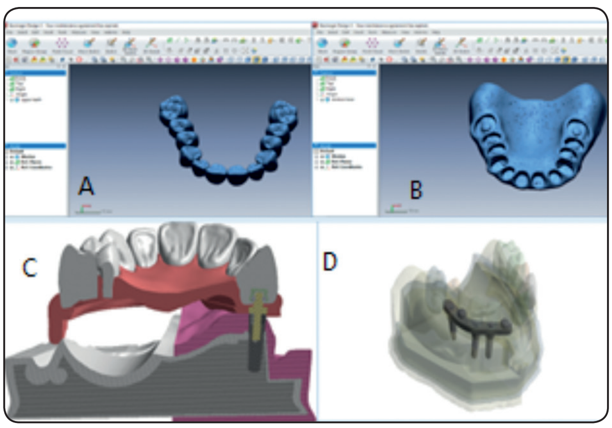

Fig. (2) Geometric model of: a) Obturator teeth ,b) Denture base c) Hollowing of the Obturator and d):Geometric model of locator/Bar implant obturator

<u>Model- I</u>: Ball attachment - implant retained maxillary obturator

<u>Model- II</u>: Novalock attachment -implant retained Maxillary obturator

<u>Model-III</u>: Locator bar with laser welded locator attachment implant retained maxillary obturator. (Fig.2-d)

Material Properties:

All materials in this study were considered to be homogenous, isotropic and linearly elastic. The modulus of elasticity and Poisson's ratio of the different materials were inserted into the software as input data. Table (1)

TABLE (1) Mechanical properties of materials used:

Material	**Modulus of Elasticity**	***Poisson's ratio***
Acrylic resin	277 Mpa	0.3
Mucosa	68 MPa	0.45
Compact bone	13700 MPa	0.3
Cancellous bone	7930 MPa	0.3
Nylon Rubber	5 MPa	0.45
PEEK caps	3 MPa	
Titanium alloy	110000	0.33

Defining Meshing:

During this process each model was divided into elements connected together at points called nodes forming an unstructured Tetrahedral Mesh. ***Fig. (3-a).*** The Total number of elements & nodes in each model is blotted in Table (2).

TABLE (2) Number of elements & nodes in studied models

Model	***Number of elements***	***Number of nodes***
Model I	9752703	12587121
Model II	10945520	11421930
Model III	13942432	12020153

Defining contacts and gaps between components:

All components were constructed to ensure 100% contact along the interfaces. A bonded contact means that these objects are displaced as one unit upon load application and the two contacting bodies can't be separated. The exception was the contact between the fitting surface of the obturator and the contacting mucosa.

Defining LOADS:

A 100 Newton Masticatory load in a vertical & oblique direction (45 degrees) was applied to the obturator prosthesis on the defect side.

- ***The vertical load*** (100 N)was directed towards the central fossae of the molar region on the defect side. (***Fig 3.b***).
- **The oblique load** (100 N) was applied in 45 degrees to the palatal inclines of the buccal cusps. ***(Fig.3.c)***
- The load was distributed over the prostheses teeth as (50 N on the first molar, 20 N on premolar area & 10 N on the canine).

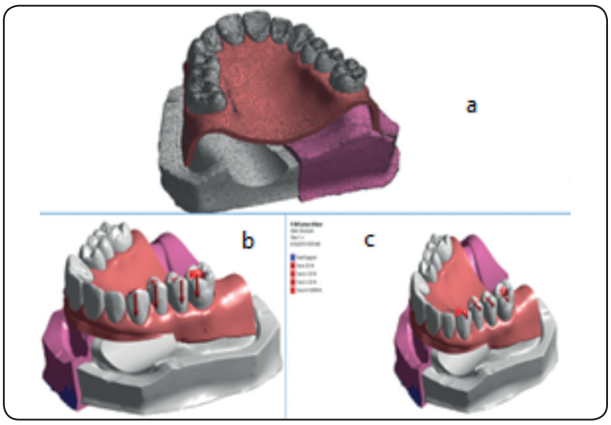

Fig. (3.a): Meshing of the geometric model

Fig. (3-b): Vertical load application on artificial posterior teeth

Fig. (3-c): Oblique load distribution & Application

Results of 3D-FEA stress analysis:

The result of each of the loading conditions for each of the three models were collected from the out-put of ANSYS program Canonsburg, PA, USA). Von Misses' equivalent stresses (S.equiv.) were selected as they are most commonly reported in FEA studies to summarize the overall stress state at a point. Consequently, the critical areas of highest stresses can be easily determined in the studied model. [22]

Results of Model (I) Implant retained maxillary obturator with Ball attachment system

Figure (4.a &4.b) are showing that the highest stresses were detected at the palatal cortical plates around the first implant , followed by the 2nd & the 3rd implant.

<u>Under oblique load:</u> Von Misses stresses values were (41.488 Mpa, 27.656 Mpa & 13.585 Mpa) around the 1st, 2nd & 3rd implants respectively.

<u>Under vertical load</u> application Von Misses stresses values were (40.762 Mpa, 27.175 Mpa, 9.62 Mpa) around the 1st, 2nd & 3rd implants respectively.

Results of Model (II): Implant retained maxillary obturator Nova lock attachment system

Figure (4.c. &4.d) are showing that the highest stresses are detected at the palatal cortical plates around the first implant, followed by the second & the 3rd implant under oblique & vertical load application on the defect side.

<u>Under oblique loading</u> Von Misses stresses values were (21.675 Mpa, 14.982 Mpa & 8.288 Mpa around the 1st, 2nd & 3rd implants respectively.

<u>Under vertical load application</u> Von Misses stresses values were (20. 479 Mpa, 10.458 Mpa, 5.447 Mpa) around the first, second & 3rd implants respectively.

Results of Model (III)- Locator /bar implant retained maxillary obturator:

Figure (5.a &5-b) are showing that the highest stresses were detected at the mesio- palatal cortical plates around the 1st implant , followed by the 2nd & the 3rd implant.

<u>Under oblique load:</u> Von Misses stresses values were (47.203 Mpa, 20. 805 Mpa & 7,608 Mpa) around the 1st, 2nd & 3rd implants respectively.

<u>Under vertical load</u> application Von Misses stresses values were (43.526 Mpa, 17.173 Mpa, 6,632Mpa) around the 1st, 2nd & 3rd implants respectively.

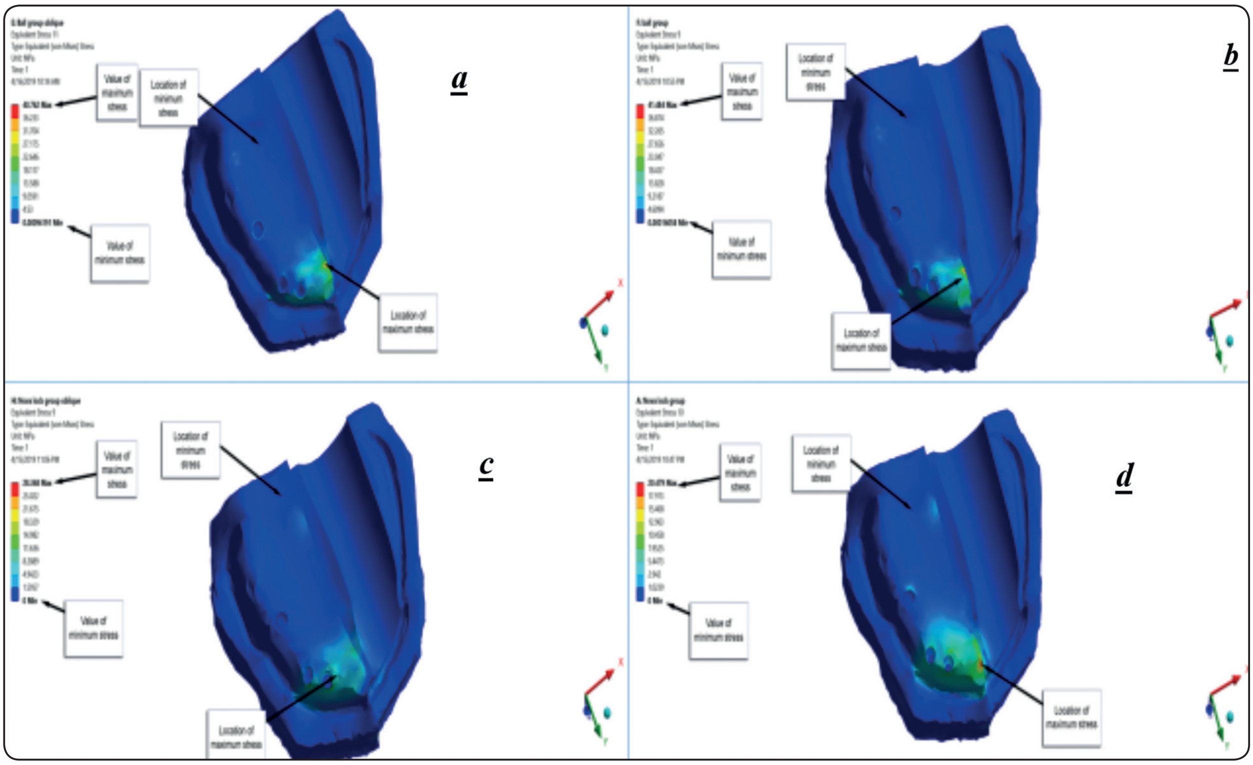

Fig. (4-a, 4-b): Stresses induced in Model-I: Ball - implant obturator under Vertical & oblique load application respectively.

Fig. (4. c &4-d):Stresses induced in Model-II : implant obturator with Novalock attachment under Vertical & oblique load application respectively

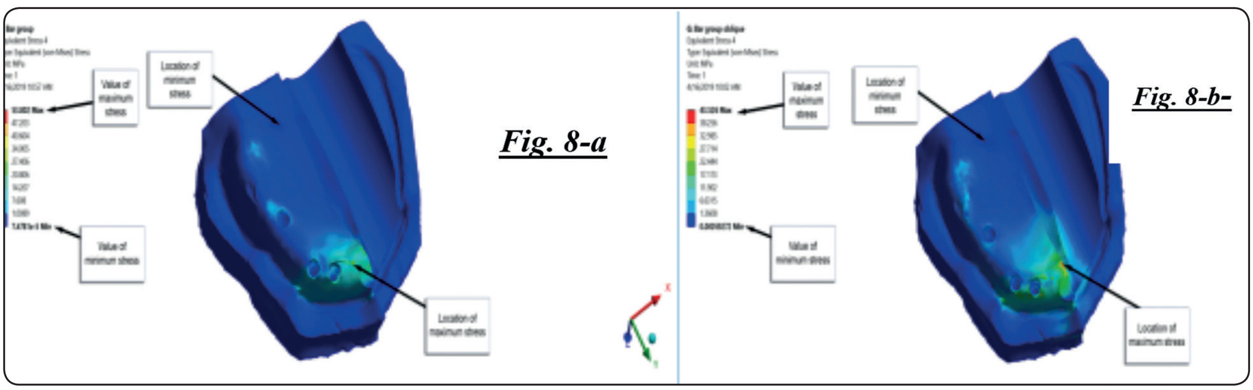

Fig. (5-a &5-b): Stress distribution pattern in locator/ bar retained implant obturator under vertical & Oblique load application on defect side respectively. (Model III)

TABLE (3): Comparison between Von Misses stress distribution pattern in the three studied models:

	Implant area	*Model (I)*	*Model (II)*	*Model (III)*
Oblique loading	*1st implant*	41.488 Mpa	21.675 Mpa	47.203 Mpa
	2nd implant	27.656 Mpa	14.982 Mpa	20. 805 Mpa
	3rd implant	13.585 Mpa	8.288 Mpa	7,608 Mpa
Vertical loading	*1st implant*	40.762 Mpa	20. 479 Mpa	43.526 Mpa
	2nd implant	27.175 Mpa	10.458 Mpa,	17.173 Mpa
	3rd implant	9.62 Mpa	5.447 Mpa	6,632 Mpa

DISCUSSION FEA OBTURATOR

In this study three dimensional FEA was made to evaluate the stress distribution pattern in implant retained maxillary obturator retained using Ball, Nova-lock and locator/Bar attachment systems. Three implants were installed in the remaining alveolar bone from the anterior to the posterior areas in a non- linear relationship to maximize stability, support, and retention.

The results of this study had revealed that the highest Von Misses stresses were recorded in the cortical bony layers surrounding the necks of the implants retaining maxillary obturtors under oblique loading in the three studied models. This finding agrees with results of previous studies as. (Jiang. et al., 2019) **[23]**

The highest stresses detected in the cortical bony layers surrounding the implant necks may be due to the higher modulus of elasticity of the cortical bone than the cancellous bone , this explains the limited ability of compact bone to absorb or dissipate forces delivered onto the implant/bone interface. This may explain for crestal bone loss that occur around implants in case of extra-load application.

Moreover, on oblique load application, the load is analyzed into vertical, horizontal & shears components. Implants are designed to tolerate the vertically applied forces and the implant-prosthetic unit can adapt to compressive forces.

However, the horizontal & shear force components tend to induce stress build-up at the implant/ bone interface. This may explain the highest stress values recorded under oblique load. Hence, in clinical application implants should be installed in a manner to avoid the destructive oblique & horizontal forces that may endanger the implant success. [24]

These results agree with, ***Jemt et al.996***[25]who conclude that the direction of occlusal forces is more influential than the connection of implants.

The highest stresses detected at the 1st implant adjacent to the maxillectomy defect might be due to the magnification of load applied by the long lever arms present after maxillary resection. This agrees with previous clinical studies that reported that crestal bone resorption is found to be higher around the implant adjacent to the defect than other implants [26,27]

The results of model -II had revealed that Novalock attachment retained implant obturators had shown the lowest Von Misses stress values, followed by Ball and Locator/ bar attachment systems.

This finding may be due to the low profile of Nova-lock attachment that may lead to decreasing the stresses transmitted onto the implant/ bone interface. Moreover, the PEEK resilient cap in the female metal housing has the lowest modulus of elasticity allowing more stress absorption & better stress distribution than Nylon caps lining the metal housing in the Ball attachment system.

Anyway, this difference between Nova-lock & ball attachments might be attributed to difference in attachment geometry.

The results of Model- I (Ball attachment) are consistent with previous studies as ***Pesqueira et al.,2013*** and ***Goiato*** et al.,***2012***[28,29], they concluded that ball attachment transmits less stresses to the implants in implant retained obturators due to the resilient characteristic of the Nylon caps female parts of the ball attachment system that absorb &distribute stress delivered to them more homogeneously.

The highest Von Misses stresses were noticed in Model -III (Locator/ Bar attachment implant retained obtuartors); This observation could be explained biomechanically as follows: one side of the oburator is supported by the bar while the defect side rests on soft tissue, which is considered as a cantilever. The presence of cantilevers increases the forces distributed to implants, possibly up to 2 or 3 times the applied load on a single implant, due to moments.**[30]**

Moreover, the bar attachment system rearranges the obturator displacement by distributing the load as the fulcrum implant will be always under compression and experiencing the highest amount of load. Meanwhile, the other implants will be under a pullout and/or compressive loads, so they show a lesser rate of bone resorption. This may explain the highest stresses detected at the area around the implant adjacent to the defect and the least stresses detected at the 3rd implant. (31)

On the other hand, stress values in model- III was lower than Bar/clip system; this may be due to the presence of Locator attachment with its low profile that play a role in dissipating occlusal loads through the abutment to the implant in a more favorable magnitude and distribution. This result is in line with Jain et al. (32)

These results of stress distribution agree ***Goiato et al.,*** (33) who evaluated the stress distribution in different implants' attachment systems (O-ring, bar-clip and bar with O-ring in distal cantilever) used in maxillary obturators by photo elastic analysis method. They concluded that the use of the association between the bar and distal O-rings favored the stress distribution.

CONCLUSIONS

Within the limitations of this study various conclusions could be drawn:

- The load direction has more important role than the attachment type in stress distribution pattern in implant retained maxillary obturators.
- Nova- lock attachment system may induce the least stresses onto implant/ bone interface followed by Ball & locator bar attachment systems.
- The Locator/ bar attachment may allow better stress distribution in implant retained maxillary obturators than other bar systems.

REFERENCES

1. Irish, J., Sandhu, N., Simpson, C., Wood, R., Gilbert, R., Gullane, P., Brown, D., Goldstein, D., Devins, G. & Barker, E. (2009) Quality of life in patients with maxillectomy prostheses. Head and Neck 31: 813–821.
2. Cheng Chena Wenhao Rena Ling Gaob Zheng Chengc Linmei Zhanga Shaoming Lia Pro Ke-qian Zhid : Function of obturator prosthesis after maxillectomy and prosthetic obturator rehabilitation Braz. j. otorhinolaryngol. vol.82 no.2 São Paulo Mar./Apr. 2016
3. Matsuyama, M., Tsukiyama, Y., Tomioka, M. & Koyano, K. (2006) Clinical assessment of chewing function of obturator prosthesis wearers by objective measurement of masticatory performance and maximum occlusal force. International Journal of Prosthodontics 19: 253–257.
4. Keyf F. Obturator prostheses for hemimaxillectomy patients. J Oral Rehabil 2001;28:821e9.
5. Kahnberg KE, Nilsson P, Rasmusson L. Le Fort I osteotomy with interpositional bone graft s and implants for rehabilitation of the severely resorbed maxilla: A 2-stage procedure. Int J Oral Maxillofac Implants 1999;14:571-8.
6. Keller EE, Tolman DE, Eckert S. Surgical-prosthodontic reconstruction of advanced maxillary bone compromise with autogenous onlay block bone graft s and osseointegrated endosseous implants: A 12-year study of 32 consecutive patients. Int J Oral Maxillofac Implants 1999;14:197-209.
7. Phoenix RD, Cagna DR, DeFreest CF. Stewart's Clinical Removable Partial Prosthodontics. Hanover Park, IL: Quintessence Pub.; 2008.
8. Keyf F.: Obturator prostheses for hemimaxillectomy patients. J Oral Rehabil. 2001; 28(9): 82.
9. Murat S, Gurbuz A, Isayev A, Dokmez B, Cetin U. Enhanced retention of a maxillofacial prosthetic obturator using precision attachments: Two case reports. Eur J Dent 2012;6:212-7.
10. Roumanas E, Nishimura R, Davis B, Beumer J. III. Clinical evaluation of implants retaining edentulous maxillary obturator prostheses. J Prosthet Dent. 1997; 77(2):184.
11. Leles CR, Leles JL, de Paula Souza C, Martins RR, Mendonça EF. Implant-supported obturator overdenture for extensive maxillary resection patient: A clinical report. J Prosthodont 2010;19:240-4
12. Fukuda M, Takahashi T, Nagai H, Iino M. Implant-supported edentulous maxillary obturators with milled bar attachments aft er maxillectomy. J Oral Maxillofac Surg 2004;62:799-805

13. Albrektsson T, Donos N. Implant survival and complications. Clin Oral Implants Res 2012;23:63e5.

14. Yokoyama S, Wakabayashi N, Shiota M, Ohyama T. The influence of implant location and length on stress distribution for three-unit implant-supported posterior cantilever fixed partial dentures. J Prosthet Dent 2004;91:234e40.

15. Stanford CM (2007) Dental implants: A role in geriatric dentistry for the general practice? J Am Dent Assoc 138: 34-40.

16. Schneider Al, Kurtzman GM (2001) : Bar overdentures utilizing the locator attachment. Gen Dent 49: 210-214

17. Herekar MG, Patil VN, Mulani SS, Sethi M, Padhye O. The influence of thread geometry on biomechanical load transfer to bone: a finite element analysis comparing two implant thread designs. Dent Res J Isfahan 2014;11:489e94.

18. DeTolla DH, Andreana S, Patra A, Buhite R, Comella B. The role of the finite element model in dental implants. J Oral Implant 2000;26:77e81

19. Porter AJ, Petropoulos VC, Brunski JB. Comparison of load distribution for implant overdenture attachment. Int J Oral Maxillofac Impl 2002;17:651e62.

20. Tokuhisa M, Matsushita Y, Koyano K. In vitro study of a mandibular implant overdenture retained with ball, magnet, or bar attachments: comparison of load transfer and denture stability. Int J Prosthodont 2003;16:128e34

21. Steven P. Haug. Maxillofacial Prosthetic Management of the Maxillary Resection Patient. Atlas Oral Maxillofacial Surg, Clin N Am 2007; 15: 51–68 Atlas Oral Maxillofac Surg Clin North Am. 2007;15(1):51-68.

22. Eraslan O, Sevimay M, Usumez A, Eskitascioglu G. Effects of cantilever design and material on stress distribution in fixed partial dentures e a finite element analysis. J Oral Rehab 2005;32:2738.

23. Jiang MY1, Wen J, Xu SS, Liu TS, Sun HQ: Three-dimensional finite element analysis of four-implants supported mandibular overdentures using two different attachments. (Abstract in English) Zhonghua Kou Qiang Yi Xue Za Zhi. 2019 Jan 9;54(1):41-45. doi: 10.3760/cma.j.issn.1002-0098.2019.01.008.

24. Naert IE, Duyck JA, Hosny MM, Van Steenberghe D. Free standing and tooth-implant connected prostheses in the treatment of partially edentulous patients part II: an up to 15-years radiographic evaluation. Clin Oral Implant Res 2001;12:245-51

25. Jemt T, Chai J, Harnett Heath MR, Hutton JE, Johns RB. A 5- year prospective multicenter follow-up report on overdentures supported by osseointegrated implants. Int J Oral Maxillofac Impl 1996;11:291-8

26. Horshaw SJ, Brunski JB, Cochran G.: Mechanical loading of Branemark implants affects interfacial bone modeling and remodeling. Int J Oral Maxillofac Implants 1994; 9:345-60.

27. Roumanas E., Nishimura R., and Beumer J. use of osseointegrated implants in the maxillary resection patient. In: Proceedings of the 1st International Congress on Maxillofacial Prosthetics. Zlotolow I , Esposito S, Beumer J ,eds.1995.

28. . Pesqueira A. A. et al., "Stress analysis in oral obturator prostheses: imaging photoelastic," J. Biomed. Opt., 18 (6), 061203 (2013). https://doi.org/http://dx.doi.org/10.1117/1.JBO.18.6.061203 JBOPFO 1083-3668 Google Scholar

29. Goiato M. C. et al., "Photoelastic analysis to compare implant-retained and conventional obturator dentures," J. Biomed. Opt., 17 (6), 061203 (2012). https://doi.org/http://dx.doi.org/10.1117/1.JBO.17.6.061203 JBOPFO 1083-3668 Google Scholar

30. Patterson EA, Burguete RL, Thoi MH, Johns RB. Distribution of load in an oral prosthesis system: an in vitro study. Int J Oral Maxillofac Implants. 1995; 10: 552-60.

31. Monaem AA, Shaker K. Use of osseointegrated implants to retain obturator s of edentulous patients. Cairo Dent J 2009;1:8

32. Jain S, Jain D, Kumar A. Comparative evaluation of stress in canine retained mandibular overdentures with three attachment designs – a 3D finite element analysis. JIDA, 2011 5: 791-793.

33. M. C. Goiato et al., "Photoelastic analysis to compare implant-retained and conventional obturator dentures," J. Biomed. Opt. 17(6), 061203 (2012