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Fatigue Lifetime of Zygomatic Implant-Supported Maxillary Prosthesis: A Finite Element Analysis

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Abstract

Purpose: To use finite element analysis (FEA) and computerized lifetime prediction algorithms to evaluate the biomechanical behavior and fatigue lifetime of a full-arch maxillary prosthesis supported by two conventional implants and two zygomatic implants in both hybrid and quad designs.

Methods: A commercially available titanium zygomatic implant system, a commercially available titanium conventional dental implant system, and a standardized sawbone human skull model were scanned using micro-computed and cone-beam computed tomography. Three dimensional (3D) models were created in Mimics. Advanced maxillary atrophy was determined on the human skull and simulated using 3D segmenting and editing tools. Finite element volume meshing was completed in Simpleware, then exported to ABAQUS where material characteristics were assigned to each respective part. The following three occlusal load scenarios were considered in this study: 1.) 150 N uniformly distributed; 2.) 150 N in the anterior region and 250 N in the posterior region; 3.) 178 N in the anterior region and 489 N in the posterior region. The von Mises stresses for each design were analyzed and plotted, and the static results were used to predict the fatigue lifetime of the zygomatic implants in FE-Safe.

Results: The maximum von Mises stress in the surrounding bone tissue was located in the crestal bone at the sites of zygomatic implants. For zygomatic implants, the maximum von Mises stress was in the abutment connection area. All values were within the bone resorption thresholding values and the limit of material strength. The fatigue lifetime for the zygomatic implants in the hybrid zygomatic implant-supported prosthesis was predicted as 1.937E+14 cycles under the maximum loading for this study. The quad-based zygomatic implant system had a lifetime prediction of 2.08E+14 chewing cycles under maximum loading.

Conclusion: Peak static stresses were found in the abutment connection of zygomatic implants and crestal bone surrounding the zygomatic implant. Therefore, additional concern should be placed on these areas, for they are most likely to fail first. The fatigue lifetime predicted for the titanium zygomatic implant in each given scenario using FE-based lifetime prediction exceeded the prediction of 40 years of service time.

Keywords: Zygomatic; Implant; Prosthesis; FEA; Fatigue

Abbreviations: Finite element analysis = FEA

Introduction

The use of dental implants is highly successful, reported at a rate of 84-92% for implants placed into sufficient and healthy bone [1]. However, a significant portion of the U.S. population faces difficulties due to compromised bone volume. Factors such as trauma, infection, and periodontal disease lend to that population. According to a study from 2013, approximately 9 million people in the U.S. face edentulism, with a prevalence of 25% in people ages 60 and older [2]. Patients suffering from edentulism face several limitations that can affect important social and psychological abilities. Along with these limitations, there are the obvious aesthetic and functional difficulties. These difficulties arise from the lack of adequate bone structure and density, and lead to reduced areas of possible implant placement. The bone cannot adequately hold the forces on and around the implant, so an increased risk of implant failure occurs [3]. Oral and maxillofacial surgeons must face the challenges of overcoming the limitations while ensuring good rehabilitation and implant success. This has remained a major issue area, for every procedure and patient is different. Procedures such as bone grafting, osteogenesis, and sinus lifting have become popular and can be used to restore the bone to an adequate amount, but each of those pose possible negative side effects [4]. Donor site morbidity, increased risk of infection, prolonged healing and treatment, multiple surgery dates, and financial burdens are all possible and likely consequences of such procedures [5].

An alternative, less invasive treatment for patients with severe maxillary atrophy is the use of a zygomatic implant-supported prosthesis. Zygomatic implants are much longer than traditional implants and extend through the sinus to engage the cortical region of the adjacent zygomatic bone [6]. The zygomatic bone provides strong anchorage for the implants that support the prosthesis [7]. This treatment eliminates the need for bone grafting or additional surgeries, which can lead to more patient morbidity and often requires general anesthesia. Additionally, there are direct benefits to the patient like lower cost and quicker rehabilitation [8]. Three previous studies have reported favorable survival rates over follow up times of 14 months, 40 months, and 10 years. Davo reported that there was a 100% survival rate of zygomatic implants in patients over an average time period of 14 months. In the same study, three conventional implants failed, so the overall result gave a 95.6% prosthesis survival rate. All prostheses were reported as functional and stable [9]. Stievenart reported a cumulative survival rate of 96% after 40 months with a quad based zygomatic approach [10]. Aparicio reported that all 22 studied patient prostheses-maintained functionality over the course of a 10-year study. 84% of the patients reported a satisfaction level over 80%, and 31.81% of the patients reported a maximum satisfaction level of 100% [11]. These follow-up studies suggest that prostheses supported by zygomatic implants seem to be a valuable technique for the rehabilitation of patients with severely atrophic maxilla.

The use of zygomatic implants has grown increasingly popular as a widely accepted and effective approach to restore severely atrophic maxilla [12]. With that said though, the research focus has been on clinical use and few studies can be found on the biomechanical effectiveness behind the clinical use. Therefore, it is of great importance to systematically explore the biomechanical behavior of the zygomatic implants, which can be done through finite element analysis (FEA) [13]. Furthermore, since this is a relatively new treatment option, existing studies cannot validate the long-term success of the use of zygomatic implants. Therefore, it is also extremely important to evaluate the long-term performance of zygomatic implant-supported prostheses, which can be done using fatigue lifetime testing [14]. Results about the biomechanical behavior and fatigue lifetime will lead to a better and more in-depth understanding of the approach, and it will lend to advances in patient specific planning and treatment. FEA is an engineering method that utilizes computerized algorithms to analyze 3-D models. It is widely used in the medical and dental industries to aid in patient treatment planning [15]. 3-D models of patient specific anatomical features are created, the models are divided into a finite number of complex shapes that are run through a series of calculations to determine the biomechanical behavior of each individual element [16].

Fatigue lifetime can be successfully predicted using data from FEA to aid in the information needed to ensure safe patient treatment [17]. The fatigue lifetime provides an approximate number of cycles that a model can exist without failure. The algorithm uses the data from the FEA to conclude the information, then the two pieces of information can be used to determine if a treatment is viable for the specific patient [18]. Therefore, the knowledge gained in this study will provide information on the biomechanical behavior of zygomatic implant-supported prostheses, as well as information on the approximate time the prostheses should last for a patient. This information can lead to improvements in clinical practice, treatment options, and patient satisfaction and comfort.

Methods and Materials

Two different implant systems were scanned using a high-resolution micro-CT scanner (Skyscan 1172, Microphotonics). The first system was a traditional 4.1 mm x 13 mm Tapered Screw-Vent Implant System (Zimmer Biomet) with a matching straight abutment, and the second system was a 4.4 mm x 42.5 mm Zygoma Machined Implant System (Nobel Biocare) with a matching 17-degree, 3 mm machined abutment. The cross-section slices acquired from the micro-CT scans were reconstructed using a volumetric reconstruction software (NRecon, Microphotonics) to generate full images. In addition to the implant scans, a standardized sawbone human skull model was scanned in a cone beam CT scanner (i-CAT, Imaging Sciences International). The implant and skull images were exported to a medical imaging engineering software (Mimics, Materialise) to perform image processing for 3-D model creations. Thresholding, cutting, and smoothing tools were utilized within the software to create full 3-D models of the skull model and each implant system.

The models of the implant systems were exported and saved as STL files. Next, to fit the need of this project, the lower mandible of the skull model was removed, and approximately 8-10 mm [19,20] was trimmed from the maxilla to simulate severe maxillary deficiency. Finally, the STL files of the implants were imported into the final 3-D skull model in two different ways to simulate potential positions within a patient facing complete edentulism. Two constructs were modeled and analyzed at the suggestion and under the guidance of Ravi Chandran, a board-certified oral and maxillofacial surgeon at The University of Mississippi Medical Center. A hybrid model was made with two traditional 13 mm implants placed in the anterior region and two 42.5 mm zygomatic implants placed in the posterior region on each side of the mouth, while a quad model was made with four 42.5 mm zygomatic

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implants. Two of the implants were placed in the premolar region on each side of the mouth, and the other two implants were placed in the molar region on each side. After all implants were positioned as needed for each construct, Boolean operations within Mimics were performed to simulate the osseointegration of the implants into the skull. Each completed construct was then exported and saved as an STL file.

The STL files from Mimics were then imported into another interactive medical modeling software (Simpleware ScanIP, Synopsis), where convergence tests were performed. The results from the convergence tests, which are seen in Figure 1 & Figure 2, determined the optimal coarseness level to be -35 for the finite element meshing of both constructs, which was used to determine the optimal mesh density setting of the models. The finite element meshing was then performed on each construct, and the resulting volume meshes were exported to a commercialized FEA software (ABAQUS, Simulia). Within ABAQUS, the material properties for the respective section of each construct were set at the values seen in Table 1. Both models were also set to be linearly elastic, homogenous, and isotropic [21]. Three different loading scenarios were considered as following to simulate the occlusal loading: 1) 150 N distributed over the full occlusal surface [22]; 2) 150 N distributed in the anterior region and simultaneous 250 N distributed in the posterior region [23]; 3) 178 N distributed in the anterior region and simultaneous 489 N distributed in the posterior region [18]. All loadings were applied uniformly to the occlusal surface of the maxillary prosthesis in the specified region. Boundary conditions pinned the base of the skull in each construct around the foramen magnum in the X, Y, and Z directions.

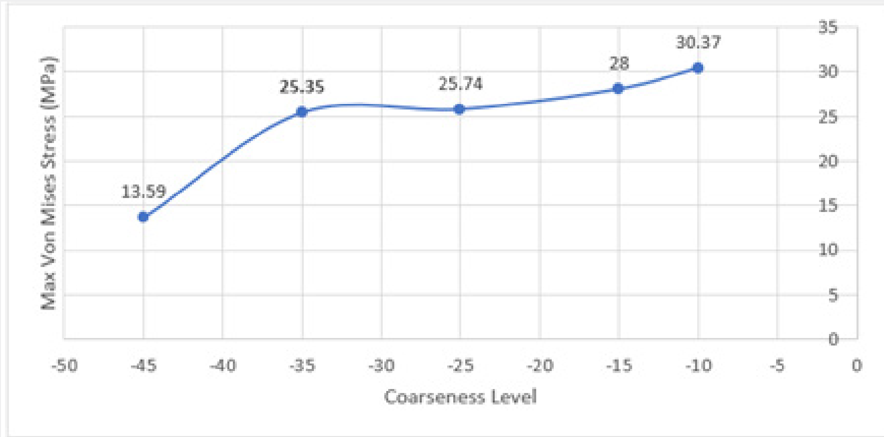

Figure 1: Convergence Test for Hybrid Model.

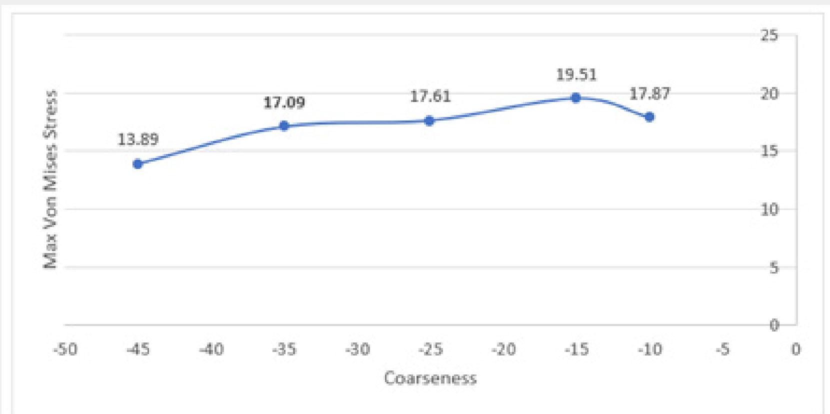

Figure 2: Convergence Test for Quad Model.

Table 1: Material Properties for FEA [14].

Bone		Implant Systems (CP Titanium)	Prostheses (Acrylic Resin)
Modulus of Elasticity (MPa)	15,000	1,20,000	2,700
Poisson’s Ratio	0.3	0.3	0.3

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Simulations were run and von Mises stresses in the implants and surrounding bone were collected. Both the numerical and the visual results were analyzed, graphed, and saved within different files. The stress results were exported to a commercially available fatigue analysis software (FE-Safe, Simulia) to predict the approximate fatigue lifetime of the implants within each construct. Fatigue analysis was run on both the hybrid and quad implant sets under the maximum loading tested. Parameters were set within the software as follows: cyclic load, implant surface finish of $0.25 < Ra <= 0.6$ micrometers [24], commercially pure titanium implant material, and Principal Strain Morrow test [25]. After running each test, an ODB file was created that contained the fatigue results measured in Log-Life Repeats. The following equation was then used:

$\log_b(a) = c$, therefore $b^c = a$

Where $b = 10$ and c was the fatigue result in Log-Life Repeats. The resulting number, a, represented the number of chewing cycles.

Results

The 3-D models of the full skull model with simulated severe atrophy are seen in Figures 3a & 3b as front and side profiles, respectively. Figures 3c-3f show the quad zygomatic approach, while Figures 3g-3j show the hybrid zygomatic approach. The two full model constructs after finite element meshing are seen in Figures 3c, 3d, 3g, 3h as front and side profiles. Close up views of the implant and prostheses systems after finite element meshing are shown in views from the front and from the top in Figures 3e, 3f, 3i, 3j. The 3-D model of the traditional 13 mm implant and subsequent 3-D finite element meshing are seen in Figure 4a & 4b, respectively. Additionally, the 3-D model and 3-D finite element meshing of the 42.5 mm zygoma implant are seen in Figure 4c & 4d.

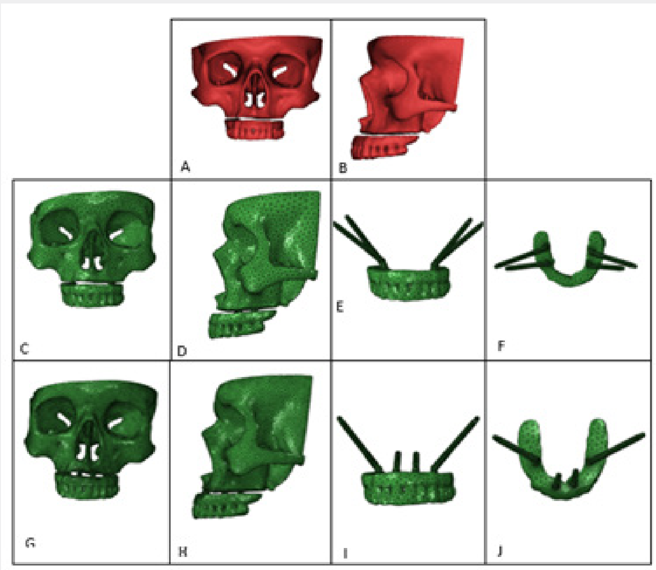

Figure 3: A) Frontal view of the composite model of the skull and prosthesis. B) Side view of the composite model of the skull and prosthesis. C) Frontal view of the quad full model. D) Side view of the quad full model. E) Frontal view of the quad implant and prosthesis system. F) Occlusal view of the quad implant and prosthesis system. G) Frontal view of the hybrid full model. H) Side view of the hybrid full model. I) Frontal view of the hybrid implant and prosthesis system. J) Occlusal view of the hybrid implant and prosthesis system.

The maximum von Mises stresses in the implants, denture, and surrounding bone under a 150 N load distributed uniformly along the occlusal surface are listed in Table 2 for both the hybrid and quad constructs. The locations of the corresponding maximum stresses are also shown within the table. The implants in the hybrid construct had the highest stress value, but the bone and denture had the highest stress values in the quad construct. All maximum stress values occurred at or within a zygomatic implant. The contour plots of the von Mises stress on the hybrid and quad implant system under the same loading is shown in Figure 5a & 5b, respectively. The charts to the left of each sub-figure show the correlation between color and stress value, with cooler colors representing lower values and warmer colors representing higher values. The part with the warmest colors is the abutment connection area of the zygomatic implant in each model.

In Table 3, the maximum von Mises stresses for each section and both constructs under a 150 N anterior load and simultaneous 250 N posterior load are shown, along with the corresponding locations. The maximum stress values for all sections, including the implants, bone, and denture, were found in the quad construct and in locations surrounding a zygomatic implant. Figure 6 shows the von Mises stress contour plots in both of the constructs under this loading. Figure 6a represents the hybrid construct and shows

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color contrasts in both the traditional implants and the zygomatic implants, but warmer colors are found in the zygomatic implants. The quad construct is seen in Figure 6b and shows warmer colors in the abutment connection area of the zygomatic implants in the front.

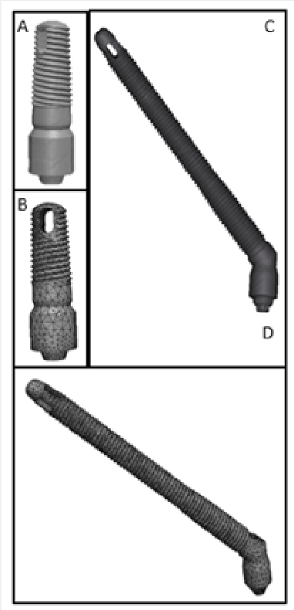

Figure 4: A) 3-D digital model of the traditional implant. B) Finite element model of the traditional implant. C) 3-D digital model of the zygomatic implant. B) Finite element model of the zygomatic implant.

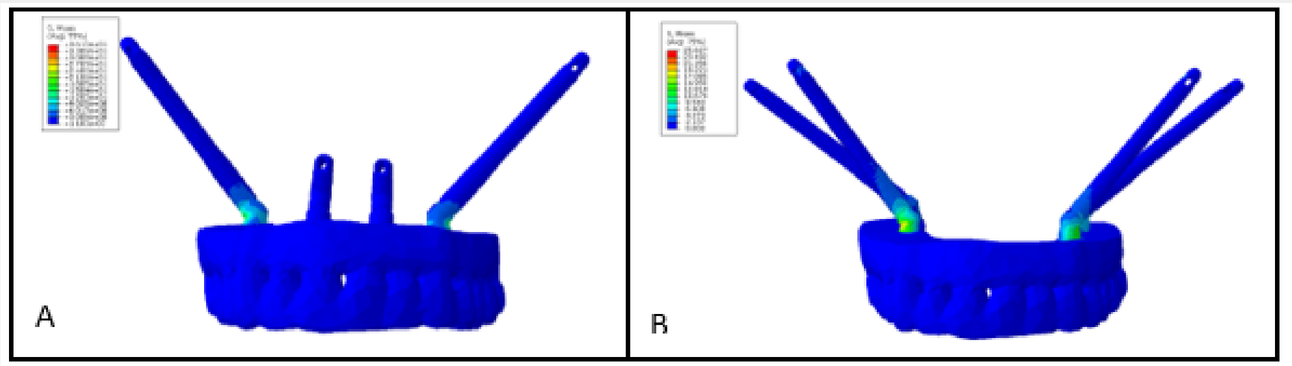

Figure 5: Von Mises stress contour plot under 150 N uniformly distributed load in the following constructs: A) hybrid; B) quad.

Table 2: Von Mises Stress and Location under 150 N Uniformly Distributed Load.

150 N Uniform	Max in Implant (MPa)	Max in Implant Location	Max in Bone (MPa)	Max in Bone Location	Max in Denture (MPa)	Max in Denture Location
Hybrid Construct	36.1	Abutment Connection of Zygomatic Implants	3.87	Crestal Bone at Zygomatic Implants	4.03	Implant Connection at Zygomatic Implants
Quad Construct	25.63	Abutment Connection of Anterior Zygomatic Implants	4.72	Crestal Bone at Zygomatic Implants	4.62	Connection at Zygomatic Implants

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Table 3: Von Mises Stress and Location under 150 N Anterior and 250 N Posterior Load.

150 N Anterior, 250 N Posterior	Max in Implant (MPa)	Max in Implant Location	Max in Bone (MPa)	Max in Bone Location	Max in Denture (MPa)	Max in Denture Location
Hybrid Construct	72.09	Abutment Connection of Zygomatic Implants	12.55	Crestal Bone at Zygomatic Implants	8.17	Implant Connection at Zygomatic Implants
Quad Construct	72.4	Abutment Connection of Anterior Zygomatic Implants	18.76	Crestal Bone at Zygomatic Implants	15.11	Connection at Zygomatic Implants

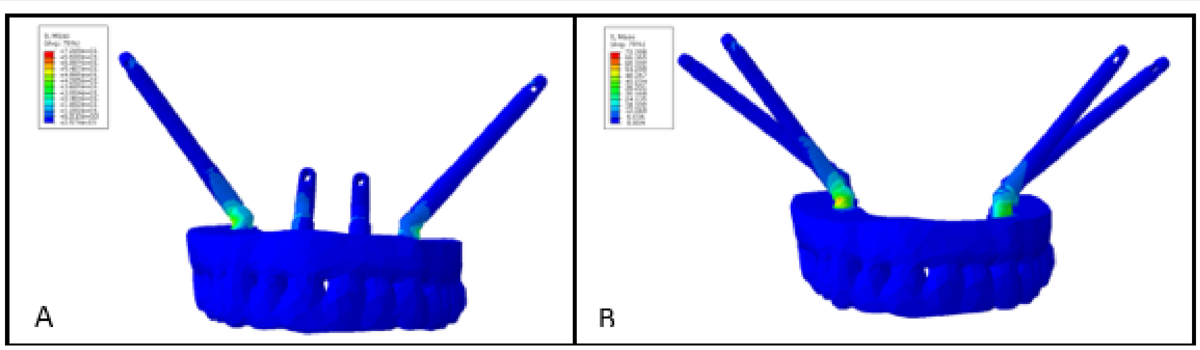

Figure 6: Von Mises stress contour plot under 150 N anterior and 250 N posterior load in the following constructs: A) hybrid; B) quad.

The maximum von Mises stresses and corresponding location under a 178 N anterior load with simultaneous 489 N posterior load is shown in Table 4. The maximum stress values within the implant systems were found in the hybrid model, while the maximum values in the denture and surrounding bone were in the quad model. Like all previous results under different loadings, the locations with the highest stresses were those at the sites of a zygomatic implant. The contour plot showing the von Mises stress of both constructs under the 178 N anterior, and 489 N posterior loading is shown in Figure 7. The hybrid model is seen in Figure 7a, while the quad model is seen in Figure 7b. The contour plots show that the warmer colors are in the zygomatic implants near the abutment connection area, while the other ends of the zygomatic implants are only the coolest color. The fatigue lifetime of the implant system in both the quad and hybrid constructs are shown in Table 5 in units of number of chewing cycles. The calculation was determined with the largest load case, which was 178 N in the anterior and simultaneous 489 N in the posterior. The quad construct was determined to withstand a higher number of chewing cycles.

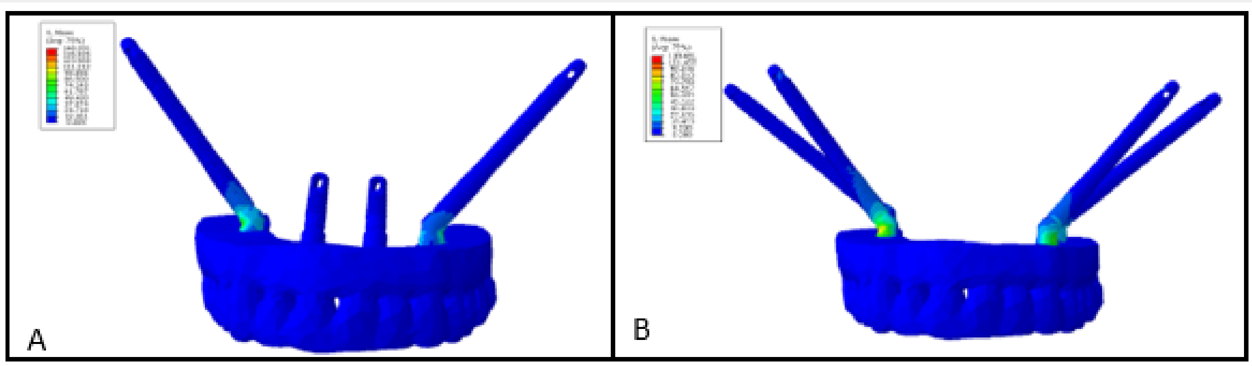

Figure 7: Von Mises stress contour plot under 178 N anterior and 489 N posterior load in the following constructs: A) hybrid; B) quad.

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Table 4: Von Mises Stress and Location under 178 N Anterior and 489 N Posterior Load.

178 N Anterior, 489 N Posterior	Max in Implant (MPa)	Max in Implant Location	Max in Bone (MPa)	Max in Bone Location	Max in Denture (MPa)	Max in Denture Location
Hybrid Construct	148.3	Zygomatic Implants	18.28	Crestal Bone at Zygomatic Implants	16.47	Implant Connection at Zygomatic Implants
Quad Construct	110.7	Abutment Connection of Anterior Zygomatic Implants	23.92	Crestal Bone at Zygomatic Implants	21.32	Connection at Zygomatic Implants

Table 5: Fatigue Lifetime Results under 178 N Anterior and 489 N Posterior Load.

178 N Anterior, 489 N Posterior	Number of Chewing Cycles
Hybrid Construct	1.94 E+14
Quad Construct	2.08 E+14

Discussion

Clinical criteria for determining hybrid or quad designs for implant rehabilitation are dictated primarily by the amount of residual bone in zones A, B, and C with zone A being the incisor, zone B the premolar, and zone C the molar locations. However, a hybrid design with straight anterior and angled zygomatic implants provides a better anteroposterior distance between the most anterior and most posterior implants (clinically referred to as an A-P spread) than the quad design with all zygomatic implants and no anterior implants. Furthermore, placement of two zygomatic implants with one in the anterolateral and one in posterolateral maxillary sinus walls is clinically more challenging than single zygomatic implant due to unique anatomical variations in sinus 3-D morphology. All else being equal, a hybrid design is surgically preferred option than a quad design.

Based on the results, the highest stress in the implants was found in the hybrid zygomatic model under the highest test load of 178 N in the anterior and 489 N in the posterior. The lowest stress in the implants was also in the hybrid model, but under the lowest test load of 150 N uniformly distributed. This was assumed, for as the load increased it was expected that stress also increased, and vice versa. While that held true, the hypothesis that one construct would be more well-suited than the other construct was not necessarily correct. The highest stress in the implants under the medium loading of 150 N in the anterior and 250 N in the posterior was found in the quad model. In short, the implants within the hybrid model were better under the minimum and maximum loads, and those within the quad model were better under the medium load. Even with that though, the resulting numbers were not greatly different. The highest stress found in the surrounding bone followed a similar trend to the stress found in the implants, where the maximum values increased as the amount of load applied also increased. The values between the quad and hybrid models between identical loadings were closer to each other in comparison to those values in the implants. Therefore, it can be concluded that the surrounding bone is not greatly affected by any increased load under the given scenarios. The results also showed that the values in the quad models were slightly higher under all load scenarios in comparison to the values in the hybrid models. While this is worth noting, the numbers are not greatly different, and the numbers do not note a likelihood of damage to the bone from either model. Therefore, under these three load scenarios, and based on the implant and surrounding bone maximum stress values, one model is not found to be more superior than the other.

As indicated in the charts, the maximum stress was within the abutment connection area of the zygomatic implants for all cases. In the hybrid cases, there are only one set of zygomatic implants, but in the quad cases, there are two sets of zygomatic implants. For those cases, the maximum stress locations were specifically in the anterior zygomatic implants. This is likely because they account for the majority of the biting force that would be spread across the anterior region of the prostheses. In contrast, in the hybrid cases, the forces are more evenly accounted for in the anterior region because of the traditional implant placement locations. The maximum in the bone was found to be in the areas surrounding the zygomatic implants.

This was expected, for the long length of the zygomatic implants creates a high bending moment that results in extra stress in the associated area. For these same reasons, the areas of the prosthesis surrounding the zygomatic implants were found to be the weakest. Recall that the maximum stress was under 150 MPa in the abutment connections of the zygomatic implants and under 25 MPa in the surrounding bone. With those numbers, there is little to no concern for implant fracture or bone damage due to stress though, for all values were within the limit of material strength for the implants and the bone resorption thresholding limit for the surrounding bone. It was reported that the yield strength for grade 4 titanium is 480 MPa [14]. Additionally, it was reported that the bone resorption threshold value is 50 MPa [26]. Therefore, both the quad and hybrid zygomatic implant-

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supported prostheses are acceptable treatments for patients with severe maxillary atrophy.

Based on the results of the fatigue lifetime tests, both constructs will last approximately 2E+14 chewing cycles under the maximum load. The maximum load was chosen because it would provide the minimum number of cycles that the constructs could survive without failure. Therefore, it is a worst-case scenario, and the constructs should actually last longer than predicted. Although the quad design has a slightly higher predicted fatigue lifetime compared to the hybrid construct, both constructs will last the entirety of a patient's life based on this study. It is reported that the average number of mastication cycles in 1 year is approximately equation to 500,000 [27]. Therefore, the number of mastication cycles in an entire lifetime would be immensely less than the experimental finding of 2E+14 cycles. The quad and hybrid models were chosen to explore for this study, but there are many other options that can be simulated and analyzed. Alterations may include types, location, and amount of both zygomatic and traditional implants. There are also much more comprehensive tests that should be performed to provide a more accurate fatigue lifetime assessment. More testing within FE-Safe, as well as real physical testing are suggested. All of these modifications and additions will provide a more comprehensive study of zygomatic implants.

Conclusion

The finite element analysis results show that zygomatic implants are a viable option for patients with severe maxillary atrophy. The highest stresses were found in the abutment connection area of the zygomatic implants and in the crestal bone surrounding the zygomatic implants, but all stress values were greatly below the corresponding threshold values. The fatigue analysis results show that both a quad and hybrid zygomatic supported prosthesis will be viable for more than the predicted 40 years. More fatigue analysis scenarios, as well as physical testing, should be completed to support this preliminary computer data.

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References

1. Sorní M, Guarinós J, García O, Peñarrocha M (2005) Implant rehabilitation of the atrophic upper jaw: a review of the literature since 1999 Med. Oral Patol Oral Cir Bucal 10(1): E45-56.
2. Emami E, de Souza RF, Kabawat M, Feine JS (2013) The Impact of Edentulism on Oral and General Health. International Journal Dentistry Int J Dent 2013: :498305.
3. Jivraj S, Chee W, Corrado P (2006) Treatment planning of the edentulous maxilla. Br Dent J 201(5): 261-279.
4. Wang F (2015) Reliability of Four Zygomatic Implant-Supported Prostheses for the Rehabilitation of the Atrophic Maxilla: A Systematic Review. Int J Oral Maxillofac Implants 30(2): 293-298.
5. Bordin D, Bergamo ETP, Fardin VP, Coelho PG, Bonfante EA (2017) Fracture strength and probability of survival of narrow and extra-narrow dental implants after fatigue testing: In vitro and in silico analysis J Mech Behav Biomed Mater 71: 244-249.
6. Nkenke E (2003) Anatomic site evaluation of the zygomatic bone for dental implant placement. Clin Oral Implants Res 14(1): 72-79.
7. Kato Y, Kizuo Y, Tonogi M, Ide Y, Yamane G (2004) Observation of the Internal Structure of the Zygomatic Bone by Micro-Computed Tomography, J. Oral Biosci 46(6): 523-529.
8. Yates JM (2014) Treatment of the edentulous atrophic maxilla using zygomatic implants: Evaluation of survival rates over 5-10 years. Int J Oral Maxillofac Surg 43(2): 237-242.
9. Davo R, Malevez C, Rojas J (2007) Immediate function in the atrophic maxilla using zygoma implants: A preliminary study. J Prosthet Dent 97(6 Suppl): S44-51.
10. Stiévenart M, Malevez C (2010) Rehabilitation of totally atrophied maxilla by means of four zygomatic implants and fixed prosthesis: a 6-40-month follow-up. Int J Oral Maxillofac Surg 39(4): 358-363.
11. Aparicio C (2014) The Long-Term Use of Zygomatic Implants: A 10-Year Clinical and Radiographic Report. Clin Implant Dent Relat Res 16(3): 447-459.
12. Aparicio C (2010) Immediate/early loading of zygomatic implants: Clinical experiences after 2 to 5 years of follow-up. Clin Implant Dent Relat Res 12(Suppl 1): e77-82.
13. Korkmaz FM, Korkmaz YT, Yaluğ S, Korkmaz T (2012) Impact of dental and zygomatic implants on stress distribution in maxillary defects: A 3-dimensional finite element analysis study. J Oral Implantol 38(5): 557-567.
14. Duan Y, Chandran R, Cherry D (2018) Influence of Alveolar Bone Defects on the Stress Distribution in Quad Zygomatic Implant–Supported Maxillary Prosthesis. Int J Oral Maxillofac Implants 33(3): 693-700.
15. Ujigawa K (20) Three-dimensional finite elemental analysis of zygomatic implants in craniofacial structures Ujigawa Int J Oral Maxillofac Surgery 36(7): 620-625.
16. Ishak MI, Ra M (2001) Intrasinus and Extramaxillary Approaches for Prosthetic Rehabilitation in Severely Atrophic Maxillae p. 3-4.
17. Duan Y, Gonzalez JA, Kulkarni PA, Nagy WW, Griggs JA (2018) Fatigue lifetime prediction of a reduced-diameter dental implant system: Numerical and experimental study. Dent Mater 39(4): 1299-1309.
18. Prados-Privado M, Prados-Frutos JC, Gehrke SA, Sánchez Siles M, Calvo Guirado JL, et al. (2016) Long-Term Fatigue and Its Probability of Failure Applied to Dental Implants. Biomed Res Int 2016.
19. Candel-Marti E, Peñarrocha-Oltra D, Bagán L, Peñarrocha-Diago M, Peñarrocha-Diago M (2015) Palatal positioned implants in severely atrophic maxillae versus conventional implants to support fixed full-arch prostheses: Controlled retrospective study with 5 years of follow-up. Med Oral Patol Oral Cir Bucal 20(3): e357-e364.

20. Degirmenci K, Kocak-Buyukdere A, Ekici B (2019) Evaluation of reliability of zirconia materials to be used in implant-retained restoration on the atrophic bone of the posterior maxilla: A finite element study. J Adv Prosthodont 11(2): 112-119.

21. Alvarez-Arenal A, Gonzalez-Gonzalez I, de Llanos-Lanchares H, Martin-Fernandez E, Brizuela-Velasco A, et al. (2017) Effect of implant- and occlusal load location on stress distribution in Locator attachments of mandibular overdenture. A finite element study. J Adv Prosthodont 9(5): 371-380.

22. Akay C, Yaluğ S (2015) Biomechanical 3-dimensional finite element analysis of obturator protheses retained with zygomatic and dental implants in maxillary defects. Med Sci Monit 21: 604-611.

23. Olesova VN, Amkhadova MA, Zaslavaskii SA, Olesov EE, Shashmurina VR (2019) Experimental Study of the Biomechanics of Maxillary Implants under Conditions of Biomechanical Modeling. Bull Exp Biol Med 166(4): 522-526.

24. Sezin M, Croharé L, Ibañez JC (2016) Microscopic Study of Surface Microtopographic Characteristics of Dental Implants. Open Dent J 10(1):139-147.

25. Kumbhar SV, Kulkarni V, Tayade RM (2014) Low Cycle Fatigue Analysis of after Treatment Device Induced due to Thermal Load by Using Finite Element Analysis. Appl Mech Mater 592-594: 1104-1108.

26. Sugiura T, Horiuchi K, Sugimura M, Tsutsumi S (2000) Evaluation of threshold stress for bone resorption around screws based on in vivo strain measurement of miniplate. J Musculoskelet Neuronal Interact 1(2): 165-170.

27. Coray R, Zeltner M, Özcan M (2016) Fracture strength of implant abutments after fatigue testing: A systematic review and a meta-analysis. J Mech Behav Biomed Mater 62: 333-346.

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