European Annals of Dental Sciences
Official Publication of Ankara University, Faculty of Dentistry

EADS, 2023, 50 (1), 35–40

e-ISSN : 2757-6744
doi : 10.52037/eads.2023.0008

Article Received/Accepted : September, 14 2022 / February, 22 2023

ORIGINAL RESEARCH ARTICLE

Comparison of Implant Systems Applied in the Mental Region in the Prosthetic Treatment of Atrophic Mandible: A 3D Finite Element Analysis

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Abstract

Purpose: This study was conducted to compare five implant-supported rehabilitation concepts of an edentulous jawbone and to investigate the most biomechanically advantageous technique.
Materials and Methods: Five models with implants in different configurations were created: All-on-4 concept (two anterior axial and two posterior distally curved implants), All-on-4v4 concept (four distal curved interforaminal implants), All-on-4W (two anterior mesial curved interforaminal implants and two posterior distally curved implants), the All-on-3 concept (one anterior axial and two posterior distally curved implants), and the trefoil system (three interforaminal implants with titanium bar guide support). For this study, bone-level (4.3 × 13 mm) implants of Nobel Biocare and implants of the trefoil system (5 × 13 mm) were used. Spherical loads were applied from the canine and molar regions to evaluate the tension, compression and von Mises stresses by applying 3D finite element analysis.
Results: Among the alternative concepts, trefoil system was the most successful treatment option in biomechanical terms. On the other hand, All-on-3 concept was found to be the last method of choice. This was because of the high stresses on cortical and trabecular bones in most conditions.
Conclusions: If the technical details of the Trefoil system are simplified in the upcoming period, it will find a very common usage area. Classical All-on-4 and All-on-4v4 techniques are the preferred and biomechanically successful treatment options today.

Key words: alveolar bone atrophy; dental implants; edentulous jaw; finite element analysis; implant-supported prosthesis

Introduction

Bone resorption, which is frequently encountered in the posterior mandible, makes implant placement a difficult task.[1–3] In such cases, posterior bone grafting methods can be considered, but they are time-consuming, costly, and risky.[4,5] For this reason, treatment options that do not require grafts are preferred and attracted by patients. The physician's experience, the patient's expectations and clinical condition determine the most appropriate treatment.

Prosthetic restorations made with support from different numbers of implants placed in the interforaminal region are frequently preferred nowadays.[6,7] Malo et al.[8] In 2003, described the 'all-on-four' (ALL4) technique that allows a fixed prosthetic restoration with four implants placed in the interforaminal region and distal implants placed at an angle. By placing longer implants and tilting the posterior two implants distally, the distal console extension is shortened and a more balanced load distribution is achieved. Subsequently, Jensen et al.[9] developed some variations on the ALL4 technique. The main idea of these variations lies in the degree of angulation of the anterior implants and posterior implants. This technique was called 'all-on-4v4' (ALL4v4) and it was suggested that even severely atrophic mandibles could be rehabilitated using this concept.

The anterior loop of the mental nerve from the radiologically detected point makes it difficult to place four implants in the interforaminal region in some patients.[10] In addition, in some patients, the triangular arch of the mandible does not allow the appropriate distance between the implants, which may require a reduction in the number of implants.[11] For such a clinical situation, the "all on three" (ALL3) technique has been developed. While two angled implants placed posteriorly at an appropriate distance from the mental foramen provide proper load distribution, while a single anterior implant application reduces the possibility of overlapping the

How to cite: Tukel HC, Geckil N. Comparison of Implant Systems Applied in the Mental Region in the Prosthetic Treatment of Atrophic Mandible: A 3D Finite Element Analysis. EADS. 2023;50(1):35-40

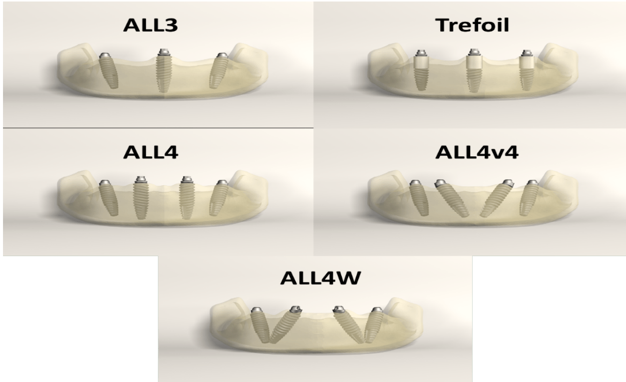

Figure 1. The Models of Our Study

apex of the posterior implants and increases operational safety.[12], [13] Finally, the trefoil system has been developed, which eliminates impression procedures and enables fixed prosthetic restoration on the day the implant is placed. This technique increases patient satisfaction by allowing rapid restoration.[14]

The main aim of this study is to reveal the most advantageous rehabilitation option among the recent trends of an edentulous mandible with severe posterior atrophy to support a fixed full-arch prosthesis using three-dimensional (3D) finite element stress analysis. This study is also a biomechanical comparison of the number of implants and the effects of inclined placement of some or all of the implants.

Material and Methods

Implant and prosthesis material properties

Bone level implants from Nobel Biocare (Zurich, Switzerland) were used in the presented 3D finite element study. The selected standard implants have a diameter of 4.3 mm and a length of 13 mm. Trefoil implants are 5 mm in diameter and 13 mm in length. In a hybrid prosthesis, a suitable superstructure was created from acrylic resin using chromium-cobalt as a metal substructure. In all models, the prosthesis consists of 12 feldspathic porcelain teeth, including the 1st molar tooth, and the dimensions are standardized for each model. The implants and denture base are attached via the manufacturer's multi-unit abutments.

Models

Five different models were created with different numbers of implants placed straight or at an angle. Models are named according to the number and configuration of implants (Figure 1).

- Model ALL3: Three interforaminal implants, only one straight and two placed at 30° angle
- Model Trefoil: Three implants with titanium bar placed in parallel with guide support
- Model ALL4: Four interforaminal implants, two straight and two placed at 30° angle
- Model ALL4v4: Four interforaminal implants placed distally at a 30° angle
- Model ALL4W: Four interforaminal implants placed at an angle of 30° anteriorly in the lateral region and posteriorly in the premolar region

Table 1. Mechanical Properties of the Materials

	Elastic Modulus (Mpa)	Poisson Coefficient
Cortical bone	13.700	0.3
Trabecular bone	1370	0.3
Implant (Ti)	100.000	0.3
Framework (Co-Cr)	218.000	0.33
Acrylic material	3.000	0.35
Feldspathic porclain	82.800	0.35

Modeling

In this study, computed tomography images of a patient with vertical atrophy in the posterior region and sufficient bone width and height in the anterior region were converted to Digital Imaging and Communications in Medicine (DICOM) format. These data were then modified again using VRMESH (VirtualGrid) and Rhinoceros 4.0 (McNeel North America) software. The models were trabecular bone covered with cortical bone in the 2 mm D2 classification and had a bone width of 8 mm along the entire alveolar crest, a bone height of 6 mm posteriorly between the mandibular canal and the alveolar crest, and a bone height of 14 mm in the interforaminal region. The distance of the right and left mental foramen from the midline was 25 mm, with a total of 50 mm interforaminal distance. A bone thickness of 1 mm was defined in the neck region of the buccal and lingual surfaces of the implants. Implants and prosthetic superstructures, scanned with an accuracy of 10 μm using a three-dimensional (3D) scanner (Activity 880, Smart Optics Sensortechnik) and transferred to VRMESH software. All structures were modeled using Rhinoceros 4.0.

Boundary and loading conditions

The boundary conditions of the presented study are modeled as constant in all directions. It was assumed that load transfers were made in accordance with the internal properties of cortical and trabecular bone. The connection between implants and supporting tissues, the connection between multi-unit abutments and implants, and multi-unit abutments and prostheses are designed to transfer loads directly. It is assumed that the osseointegration success of the implants is 100%. All materials used in this study were defined as homogeneous, isotropic and linear elastic. (Table 1). Two occlusal loads (100 N) were applied to each model using a spherical solid material (12 mm in diameter) placed on the left canine and left first molars to visualize chewing forces more naturally (Figure 2).

Analysis

Fundamental stresses were evaluated for structures with low elasticity such as bone. Maximum principal stress (Pmax) represents tensile forces, while minimum principal stress (Pmin) represents compression forces. Von Mises stress analysis was performed to evaluate the stress generation in the implants. In this study, Pmax, Pmin and von Mises voltages were measured in megapascals (MPa). Data analysis was performed with ALGOR FEMPRO (Algor Inc. Pittsburgh, USA) software. Since the data obtained from the finite element analysis are mathematical calculations without variance, statistical analysis of the results is not performed; evaluated with scales instead. All stress values were evaluated comparatively using color and quantity scales.

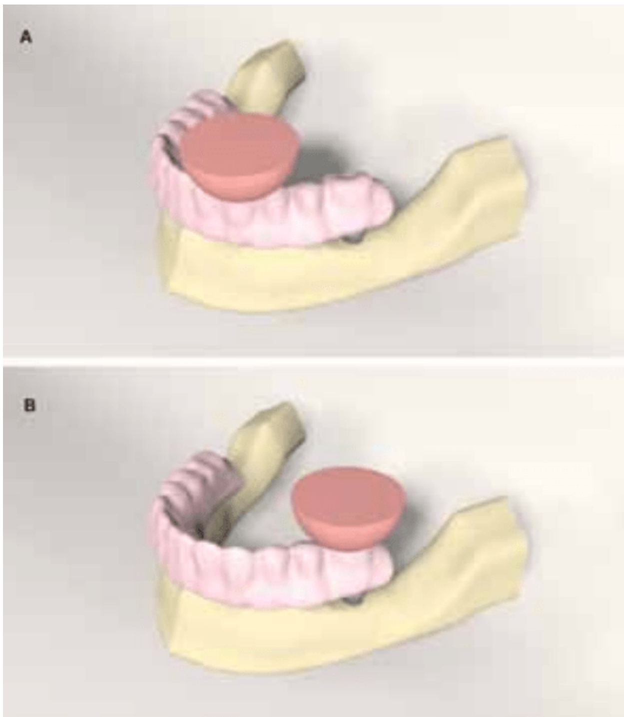

Figure 2. (A) Spherical Loading Applied From the Canine Region. (B) Spherical Loading Applied from the Molar Region

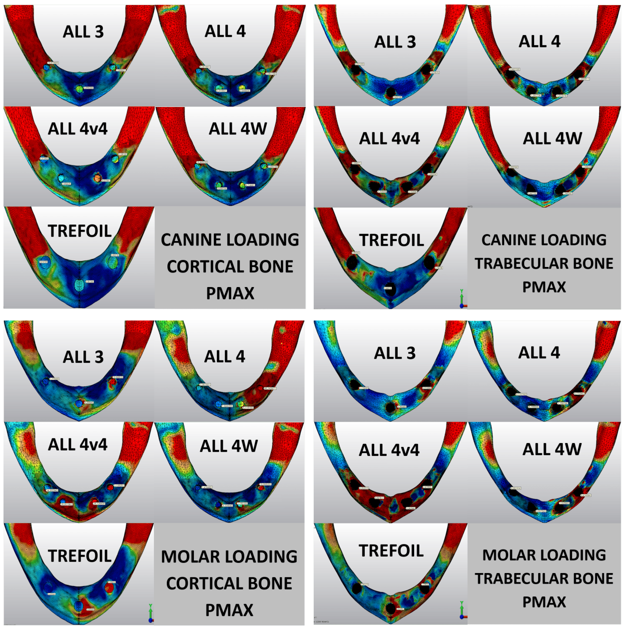

Figure 3. Tension Stresses (Pmax) in Cortical and Trabecular Bone Against Loadings from the Canine and Molar Regions

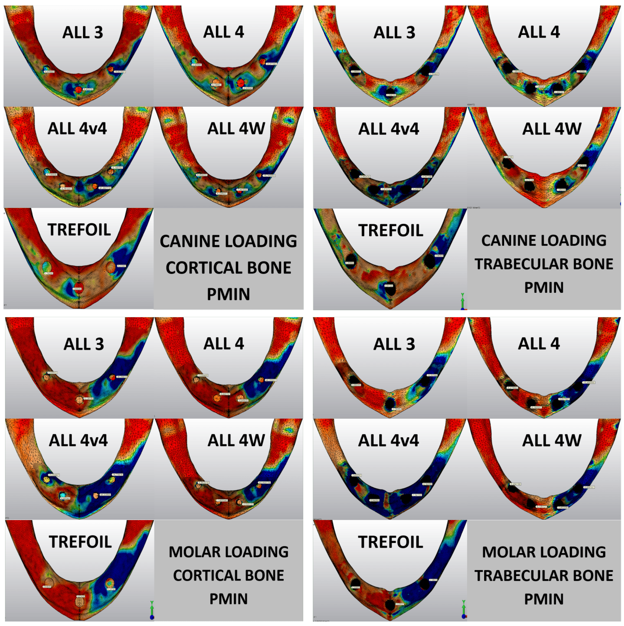

Figure 4. Compression Stresses (Pmin) in the Cortical and Trabecular Bones Against Loadings from the Canine and Molar Regions

Results

Maximum Principal Stresses

When the stresses in the cortical bone were evaluated against the forces applied from the canine region, the highest stress was seen in the ALL4W model with 18.4 MPa, and the lowest stress was observed in the trefoil model with 0.56 MPa. It was observed that the trefoil model produced much lower stress than the other three models. While the highest 4.9 MPa stress was observed in the trabecular bone in the ALL3 model, the lowest stress with 0.04 MPa was also observed in the Trefoil model. Considering the stresses in the cortical bone in the molar region, the highest stress was observed at 40.14 MPa in the ALL4 model, while the lowest stress of 0.43 MPa was observed in the trefoil model. The highest value in the trabecular bone was observed in the ALL3 model with 6.81 MPa. The trefoil model produced the lowest voltage at 0.35 MPa, about one-fifth of the closest voltage value (Figure 3).

Minimum Principal Stresses

When the stresses occurring in the cortical bone were evaluated against the forces applied from the canine region, the highest stress value of −23.9 MPa was observed in the ALL4 model. The lowest stress of -1.7 MPa was observed in the trefoil model. The highest stress in the trabecular bone was observed in the ALL3 model with −6.3 MPa, and the lowest stress was observed in the ALL4W model with −0.2 MPa. When the stresses on the cortical bone were evaluated against the forces applied from the molar region, the highest stress was observed in the ALL4v4 model with −68.3 MPa, and the lowest stress was observed in the trefoil model with −0.06 MPa. In the trabecular bone, the highest stresses on average of −10.3 MPa were observed in ALL3 and ALL4 models, while the lowest stress of −0.2 MPa was also observed in the trefoil model (Figure 4).

Stresses in Implants (Von Mises Stresses)

When the stresses formed on the implants as a result of the forces applied from the canine region were evaluated, the lowest stress was measured in the trefoil model with 4.6 MPa, and the highest stress was measured in the ALL4 model with 546.9 MPa. The other three models presented similar stress values. The highest stress against the forces applied from the molar region was seen in the ALL4v4 model with 116.3 MPa, and the lowest stress was observed in the trefoil model with 9.5 MPa. The mean tensile strengths in the molar region of the other models were close to each other (Figure 5).

Figure 5. Von Mises Stresses on the Implants in Models Against Loadings from the Canine and Molar Regions

Discussion

The models studied with the trefoil system showed lower stress and a more balanced stress distribution in both trabecular and cortical bone compared to the other models in the study. When the compressive and tensile forces were evaluated together, the ALL3 model showed higher stress values compared to other models. According to this result, loading on three implants without using a different technology may negatively affect the treatment results. The ALL4W model, in which anterior implants were placed mesially inclined, caused particularly high stress on cortical bones. The ALL4v4 model, which is another variant of the ALL4 model, stands out as a good alternative to the ALL4 model, except for the high stress on the cortical bone against the forces in the molar region. These results suggest that the distal angulation of the implant provides an advantage in terms of resistance to forces. Finite element analysis is a method used to reveal stress values on complex structures in a simple and understandable way. Under normal conditions, clinical verification of loading-induced stresses is impossible. However, 3D finite element analysis makes it possible to examine the forces around dental implants and bones in three dimensions.[15–17]

While the contemporary methods in recent years is the variants of four implant supported fixed prosthesis, some surgeons aim at prosthetic rehabilitation by reducing the number of implants. However, full-arch fixed mandibular prostheses supported by fewer implants still raise doubts about the prognosis of the treatment.[18] For this reason, the Treofil system was defined with the promise of fewer implants and faster treatment.[14] This method, which is also interesting in terms of patient compliance, was included in our study to investigate the reliability of treatment.

The trending method for the rehabilitation of edentulous and posterior atrophic jaws is the placement of four osseointegrated implants in the interforaminal region of the edentulous jaws.[1] Although the reported success rates for this technique are high,[19–21] long cantilever size can cause technical complications, especially in prosthetic materials.[22–24] For this reason, in recent years, distally anglulated implant placement studies have been carried out in order to benefit from the interforaminal space that is anatomically and physiologically suitable for implant placement and to reduce the cantilever length.[8,12,22,25,26] Following the publication of the long-term treatment results of the ALL4 method by Malo et al, other authors also confirmed the high success rates of this protocol.[8,23]

After the ALL4 concept gained popularity, Jensen et al.[9] proposed a modification to this technique for severely atrophic mandibles. In this technique, known as ALL4v4, they placed two axially placed anterior implants parallel to posterior angled implants. The researchers emphasized that this modified technique could be superior to the ALL4 concept by reducing the risk of fractures in atrophic mandibles, providing higher insertion torque values and allowing longer implants to be placed. In addition to the ALL4 technique and the All4v4 technique, an ALL4 modification in which anterior implants are angled anteriorly to each other is also included in this study.

The Branemark Novum Concept includes the procedure for reducing the number of implants, eliminating the need for impressions and attaching a permanent fixed bridge on the day of implant placement.[6,7,27] Clinical practice and shortening of the patient's edentulous period may come to the fore as the reason for preference for the method. In a recent clinical study, the amount of peri-implant resorption was found to be within the expected limits in a fixed restoration on three implants.[28] In our study, the stresses on the implant in the ALL3 model were found to be similar or lower than in other models. This result is clinically correlated with tolerable peri-implant bone loss in fixed prosthetic restoration on three implants.

An important point to note here is the amount of stress the system exerts on the bone. Considering the results of the study, the amount of stress on the trabecular bone is high in both canine and molar regions in the ALL3 model.

Developed by Nobel Biocare (Nobel Biocare, Zurich, Switzerland), the trefoil system is a customized version of the Branemark Novum Concept. Prefabricated components has the advantage of reducing the active working time to approximately six hours from the beginning of the surgery until the screwing of the prosthesis on the same day. On the other hand, the surgical protocol is not as simple as it sounds and the clinician must be well trained to manage any intraoperative complications.[14] Considering the results presented in the study, the lowest stresses in cortical and trabecular bone were observed in the trefoil model. The low stress generation in both canine and molar regions indicates that this system will bring successful results when used with the right indication and appropriate surgical technique.

When the ALL4 model and variants were compared, no significant difference was observed between the stresses. The ALL4 approach, where the stress is more intense on the implants and in the molar region, may be replaced by the ALL4v4 approach if supported by new research. In the ALL4W model, where the anterior implants are angled in the opposite direction, a prominent advantage of force distribution was not observed.

Conclusion

It was observed that among the four implant-supported full-arch fixed rehabilitation alternatives for a completely edentulous mandible, classical ALL4 and ALL4v4 techniques came to the fore. It was predicted that the opposite inclination of the anterior implants would not increase the success of the treatment. On the other hand, it was observed that the ALL3 concept, which reduced the cost and surgical time, placed more stress on the trabecular bone.

The stresses transmitted to the bone and met by the implants were observed at least in the Trefoil system. It was envisaged that this system, which is a different application technique with prefabricated parts, can be preferred for saving time and cost, as well as restricting the use of the surgical procedure that requires delicacy. It will be useful to support the existing findings and compare different techniques with future experimental and clinical studies. However, it should be noted that clinical results may not always be consistent with FEM studies. Important details in the application of techniques, surgical experience, oral hygiene, actual direction and intensity of forces, and costs may limit the use of the techniques investigated. For this reason, long-term clinical studies are needed.

Acknowledgements

The authors would like to thank Sercan Kucukkurt for support in the finite element analysis.

Author Contributions

H.C.T.: Obtaining the results with the idea, project, analysis technique of the research article. N.G.: Literaturereview, writing the study, evaluation of the results.

Conflict of Interest

The authors deny any conflicts of interest related to this study.

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