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ABSTRACT

of the dissertation for the degree of Doctor of Phylosophy

ANALYSIS OF STRESSES IN THE IMPLANT AND TISSUES SURROUNDING IMPLANT DURING THE USE OF PROSTHESES ON IMPLANTS

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Field of science:	Medicine
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GENERAL CHARACTERISTICS OF THE DISSERTATION WORK

Relevance of the topic. Prosthetics on implants, considered one of the components of the subject of orthopedic dentistry is a method of restoring teeth lost for one reason or another, and has a long history of development. Prostheses on implants gives advantsgeous opportunities for the restoration of defects caused by various reasons in the tooth row. Prosthetics on implants has its own subtleties in various defects of the tooth row. In recent years, implantable prostheses have been preferred compared to removable prostheses in in orthopedic treatment of people with complete adentity. A surgical procedure performed without proper pre-planning can lead to improper implant placement, which in turn can cause appearing of function, durability, aesthetics and other problems. When excessive stresses occur in bone tissue surrounding the implant, bone tissue cannot react in the degree to compensate it, atrophy occurs, bone loss begins, the implants loosen and their stability is disturbed. Improperly planned surgical intervention, as well as the corresponding bar construction and its cantilever protrusions create a foundation for a number of problems in the future. Among these complications, the excessive stress placed on the implants during chewing can lead to the loss of the more stressed implant over time. Similarly, not correctly determining the length of the cantilever protrusion of the bar structure will cause deformations in the bar system itself in the future, as a result of which the stress transmitted to the implants will be slightly increased.

Implant, abutment, prosthesis on implant and other fixing systems are determined during prosthetics by implantation. Modern dental implants are complex mechanical constructions that contain a combination of different materials. For designing such constructions, experimental, mechanical and mathematical modeling is needed. Modeling is an important step in evaluating the mechanical properties of implants under loading with real masticatory forces. Application of the finite element method has been widespread in recent years for the purpose of mechanical and mathematical modeling of many factors related to the use of dental implants. Finite element method (FEM) is a numerical solution method of applied physics. The corresponding method is widely used in mechanics of deformable solids, heat exchange processes, hydrodynamics and electrodynamics. At this time, the solution of the technical problems that are difficult to solve is carried out approximately with the help of elliptic differential equations with boundary conditions. The essence of the method is that it looks at the set of functions defined in separate subfields to minimize the functionality of the problem, and the digital analysis of the system considers it as a complete unit. The emergence of the finite element method is related to the solution of space problems in the 50s. Although this method is known from construction mechanics and stiffness theory, its mathematical foundations were developed later, and its application fields were further expanded starting from the 60s.[1][2][3][4]

A number of scientific research has been carried out in this direction. In one of these studies, the pressure on implants made of various materials was studied, and as a result, it turned out that the pressure on implants with a high modulus of elasticity with titanium content is higher than on ceramic ones. In this case, the maximum displacements in structural elements were recorded in ceramic-based

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[1] N.Panahov, R.Huseynli. Orthopedic density. Prosthetics on implants, (2021) page 31-39.

[2] Grzeskowiak RM, Schumacher J, Dhar MS, Harper DP, Mulon P-Y and Anderson DE (2020) Bone and Cartilage Interfaces with Orthopedic Implants: A Literature Review. Front. Surg. 7:601244. doi: 10.3389/fsurg.2020.601244.

[3] De Sousa Ferreira V.C., A.P. Lopes, N.M. Alves, F.R.N. Sousa, K.M.A. Pereira, D.V. Gondim, V.C.C. Girão, R.F.C. Leitão, P. Goes Bisphosphonate-related osteonecrosis induced change in alveolar bone architecture in rats with participation of Wnt signaling Clin Oral Investig., 25 (2) (2021), pp. 673-682

[4] Bourauel C., M. Aitlahrach, F. Heinemann, and I. Hasan, “Biomechanical finite element analysis of small diameter and short dental implants: extensive study of commercial implants,” Biomedizinische Technik/Biomedical Engineering, vol. 57, no. 1, pp. 21–32, 2012. https://doi.org/10.1515/bmt-2011-0047

models, and the minimum displacements were recorded in titanium-based models. [5][6][7][8]

To prevent the implant from overloading after osteointegration, it is very important to know how the stress caused by the specified force spreads to the implant and the tissues around the implant, as well as the side effects caused by these stresses on the tissues around the implant. Understanding the mechanism of transfer of force from the implant to the tissues surrounding the implant is an important factor in determining the life of the implant. This is because excessive stress can lead to implant osteointegration failure, fractures in the implantable structure and resorption in the implantable bone.

Subject of the study: According to the Keller classification patients with II type chin atrophy

The aim of the study is to improve the efficiency of treatment of toothless patients with implantable prostheses.

The study objectives:

1. Study of stress indicators such as expansion and compression recorded in the cortical bone layer during masticatory forces applied from the anterior, right- and left-posterior regions on different virtual jaw models by using the finite element analysis method;
2. Determination of stress indicators such as expansion and compression recorded in the cancellous bone layer after application

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[5]Ellendula Y, Chandra Sekar A, Nalla S, et al. (April 29, 2022) Biomechanical Evaluation of Stress Distribution in Equicrestal and Sub-crestally Placed, Platform-Switched Morse Taper Dental Implants in D3 Bone: Finite Element Analysis. Cureus 14(4): e24591. doi:10.7759/cureus.24591

[6] Messias, M. A. Neto, A. M. Amaro, V. M. Lopes, and P. Nicolau, "Mechanical evaluation of implant-assisted removable partial dentures in Kennedy class I patients: finite element design considerations," Applied Sciences, vol. 11, no. 2, Article ID 659, 2021. https://doi.org/10.3390/app11020659

[7] Reda, R.; Zanza, A.; Galli, M.; De Biase, A.; Testarelli, L.; Di Nardo, D. Applications and Clinical Behavior of BioHPP in Prosthetic Dentistry: A Short Review. J. Compos. Sci. 2022, 6, 90. https://doi.org/ 10.3390/jcs6030090

[8] Aunmeungtong W., Khongkhunthian P., Rungsiyakull P. Stress and strain distribution in three different mini dental implant designs using in implant retained overdenture: a finite element analysis study. Oral Implantology .2016;9:202–212. doi: 10.11138/orl/2016.9.4.202.

of masticatory force applied from the anterior, right- and left-posterior regions;
3. Examining the stress indicators on the implants during masticatory forces applied from the anterior, right- and left-posterior regions around the implant;
4. Determining the stresses on the bar attachment of the orthopedic construction due to the influence of chewing pressure in different directions.

Research methods

CBCT – – radiography method, finite element stress analysis method, statistical processing.

The main provisions of the defense:

- The finite element method can be used to analyze the stresses generated in implant and peri-implant tissues during the use of the implanatable prostheses.
- During the implantable prosthetics, the height levels of the alveolar protrusion of the jaw bone have a role in the success of the implantation and the stress indicators on the implants.
- Placement of implants at right angles to the bone tissue and maximally parallel to each other during post-implant prosthetics has a good effect on the more even distribution of stress between the elements and, as a result, on the success indicators of the treatment.

Scientific novelty of the study:

- Stresses on the implants, on the post-implant orthopedic construction, and on the peri-implant cortical and cancellous bone layers due to the impact of the protruding prosthetic construction resting on 4 implants in the atrophied edentulous jaw were investigated.
- Based on the results of the research, the most optimal options of dental implantation and the construction to be prepared were proposed in the preparation of over-implant prosthesis using 4 implants in the atrophied jaw.

Practical significance of the study:

Based on the evaluation of the results of our scientific research, the effectiveness of the orthopedic treatment of the toothless jaw with implantable prostheses has been confirmed and the sequence of its use in the clinic has been determined.

Approbation. The results of the research were discussed at the following conferences:

"XXIV Republican Scientific Conference of Doctoral Students and Young Researchers" dedicated to the 880th anniversary of Nizami Ganjavi, Baku 2021; International scientific-practical conference dedicated to the 100th anniversary of Heydar Aliyev on Modern Medicine: Innovations and Modern Approaches, Baku 2023; Analysis of the impact of implant prosthetics on the implant and peripheral tissues on various models, Practice Oriented Science UAE-Russia India, UAE 2022.

-The dissertation work was reported and extensively discussed at the meetings of the Department of Orthopedic Dentistry of AMU dated 16.11.2023 No. 38 and 3226.01 - "Dentistry" specialty scientific seminar operating under the ED 2.50 Dissertation Council No. 07 dated 10.01.2024 .

Application of the results of the work in practice. The scientific and experimental results obtained from the research were applied in the educational process of the Department of Orthopedic Dentistry of AMU and the experimental activity of the Teaching Dental Clinic of AMU.

Name of the organization where the dissertation work was performed. The research work was performed at the Department of Orthopedic Dentistry of Azerbaijan Medical University and the laboratory of "AY-Tasarım LTD" in Ankara.

Publication. The results and fragments of the dissertation were reflected in 9 scientific works, including 6 articles and 3 theses. 2 articles and 1 thesis out of these works were published abroad.

The volume and structure of the dissertation. The dissertation consists of the introduction (4934 characters), literature summary (12841 characters), personal research and their discussion (189012 characters), conclusion (1333 characters), practical recommendations (667 characters) and reference list (20 pages). The reference list contains 185 sources.

9 tables, 12 graphs, 2 schemes and 18 figures are included in the thesis work. The volume of the work consists of 162 pages (202167 characters).

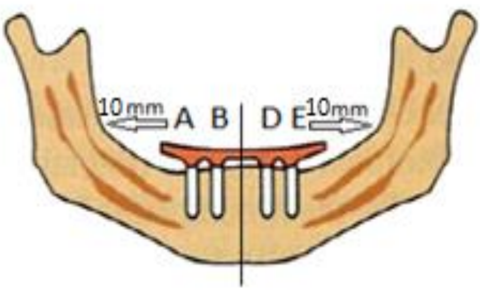
MATERIALS AND METHODS OF THE RESEARCH

The research work was perfomed at the Department of Orthopedic Dentistry of Azerbaijan Medical University and the laboratory of "AY-Tasarım LTD" in Ankara.
During the research, a computer equipped with an Intel Xeon CPU 3.30 GHz processor, 500 GB Hard Disk, 14 GB RAM and Windows 7 Ultimate Version Service Pack1 operating system, 3D scanning with an Activity 880 (Smart optics sensortechnik GmbH, Sinterstrasse 8, D-44795, Boxhum, Germany) optical scanner, Rhinoceros 4.0 (3670 Woodland Park Avenue Seattle, WA 98103 VSA) 3D modeling software was used was used for the preparation of 3D digital models, their homogenization and the application of finite element analysis method. The models were geometrically shaped with VRMesh (VirtualGird Inc, Bellevue City, WA, USA) and loaded into Alger Fempro (ALGOR, Inc. 150 BetaDrivePittsburgh, PA 15238-2932 USA) in STL format for analysis. The STL format is very important for 3D modeling. Due to the storage of node coordinate data in STL format, data exchange between programs, in other words, no data loss occurs when performing data transfers. After the Algor program has been adjusted to the required condition, the model formed belongs to the mandibular bone, the implant, over-implant prosthesis, etc. to be used. It is necessary to introduce to the program what material the other structures to be used are made of. Each of the structures that make up the models is given indicators such as the modulus of elasticity and Poisson's ratio, which contain their physical indicators. The meshing process uses 8-node (brick-type) 3D elements whenever possible.

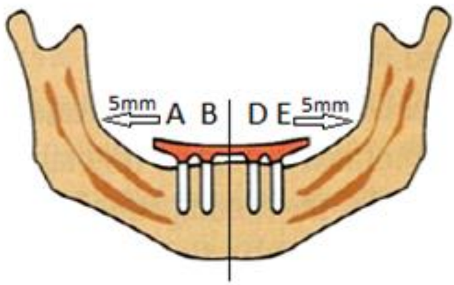
In the central parts of the structures in the models, 3D elements with less nodes are used when necessary so that the structure can be fully meshed. With this meshing technique, we generate the highest quality mesh structure with the highest number of nodes possible to simplify computation. We use 8-node 3D elements as much as we can fit in our models, but we also use 7-node, 6-node, 5-node, and 4-node 3D elements when needed in regions with finer details.

Below are the structures of 10 different 3D models.

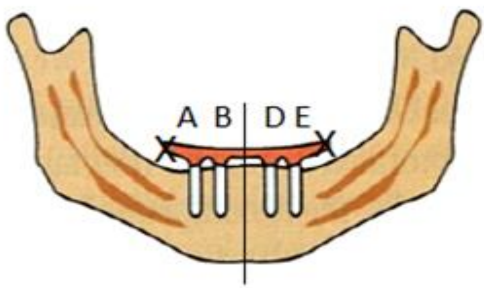
Model 1. (Control group) Implant B is placed 5 mm to the right of the midline, implant A is 7 mm to the right of implant B, implant D is placed 5 mm to the left of the midline, and implant E is placed 7 mm to the left of implant D in the jaw we apply. Elevation levels are the same for all implants. The angles of location with the bone are 90 degrees. The cantilever length of the bar attachment is 10mm.



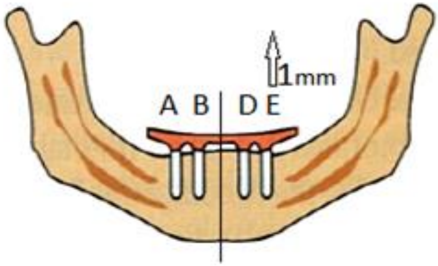
Model 2. Implant B is placed 5 mm to the right of the midline, implant A is placed 7 mm to the right of implant B, implant D is placed 5 mm to the left of the midline, implant E is placed 7 mm to the left of implant D. Elevation levels are the same for all implants. The angles of location with the bone are 90 degrees. The cantilever length of the bar attachment is 5 mm.



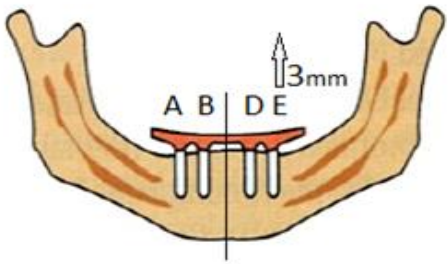
Model 3. Implant B is placed 5 mm to the right of the midline, implant A is 7 mm to the right of implant B, implant D is placed 5 mm to the left of the midline, and implant E is placed 7 mm to the left of implant D. Elevation levels are the same for all implants. The angles of location with the bone are 90 degrees. The cantilever length of the bar attachment is 0 mm (without cantilever).



Model 4. Implant B is placed 5 mm to the right of the midline, implant A is 7 mm to the right of implant B, implant D is placed 5 mm to the left of the midline, and implant E is placed 7 mm to the left of implant D in 1 mm height (in accordance with the bone relief. Elevation levels of the remaining implants are the same for all implants. The angles of location with the bone are 90 degrees. The cantilever length of the bar attachment is 10 mm.

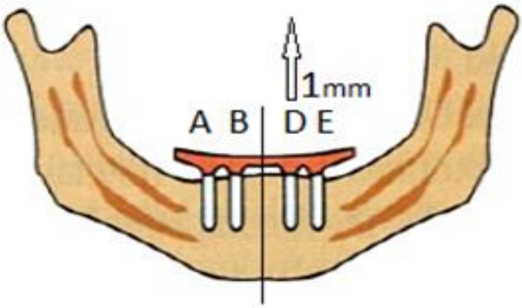


Model 5. Implant B is placed 5 mm to the right of the midline, implant A is 7 mm to the right of implant B, implant D is placed 5 mm to the left of the midline, and implant E is placed 7 mm to the left of implant D. Elevation levels are the same for all implants. The angles of location with the bone are 90 degrees. The cantilever length of the bar attachment is 0 mm (without cantilever).

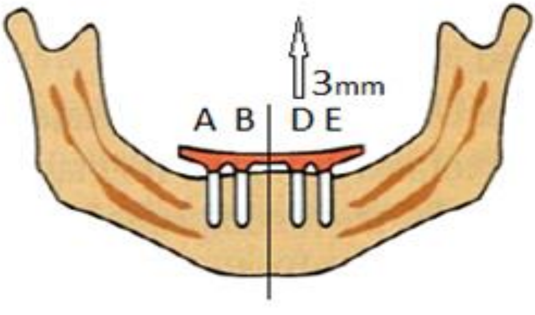


Model 6. Implant B is placed 5 mm to the right of the midline, implant A is 7 mm to the right of implant B, implant D is placed 5 mm to the left of the midline, and implant E is placed 7 mm to the left of implant D in 1 mm height (in accordance with the bone relief). Elevation levels of the remaining implants are the same for all

implants. The angles of location with the bone are 90 degrees. The cantilever length of the bar attachment is 10 mm.

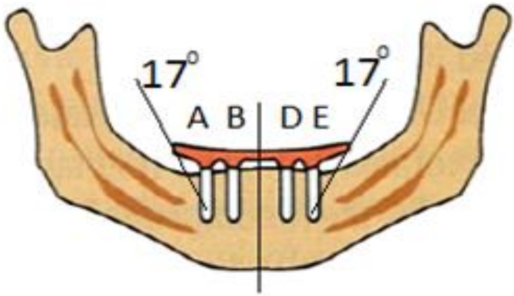


Model 7. Implant B is placed 5 mm to the right of the midline, implant A is 7 mm to the right of implant B, implant D is placed 5 mm to the left of the midline, and implant E is placed 7 mm to the left of implant D in 3 mm height (in accordance with the bone relief). Elevation levels of the remaining implants are the same for all implants. The angles of location with the bone are 90 degrees. The cantilever length of the bar attachment is 10 mm.

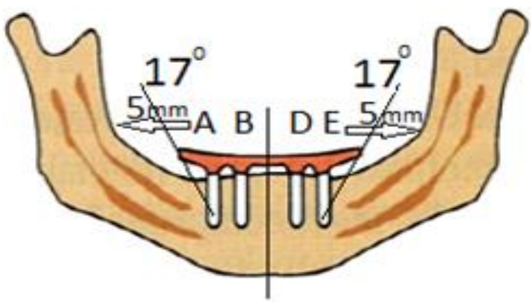


Model 8. Implant B is placed 5 mm to the right of the midline, implant A is 7 mm to the right of implant B, implant D is placed 5 mm

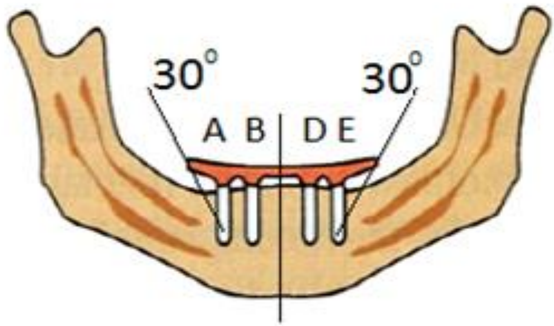
to the left of the midline, and implant E is placed 7 mm to the left of implant D. Elevation levels for all the implants are the same. The angles of location with the bone are 90 degrees for B and I implants, 17 degrees for A and E implants. The cantilever length of the bar attachment is 10 mm.



Model 9. Implant B is placed 5 mm to the right of the midline, implant A is 7 mm to the right of implant B, implant D is placed 5 mm to the left of the midline, and implant E is placed 7 mm to the left of implant D. Elevation levels are the same for all implants. The angles of location with the bone are 90 degrees in B and D implants and 17 degrees in A and E implants. The cantilever length of the bar attachment is 10 mm.



Model 10. Implant B is placed 5 mm to the right of the midline, implant A is 7 mm to the right of implant B, implant D is placed 5 mm to the left of the midline, and implant E is placed 7 mm to the left of implant D. Elevation levels for all implants are the same. The angles of location with the bone are 90 degrees in B and D implamants while 30 degrees in A and E implants. The cantilever length of the bar attachment is 10 mm.



Thus, in the research we conducted on 10 different models, the force to be applied was considered a virtual equivalent of weighing a 1 cm hard food mass with a force of 100N (about 10.2 kg). The force was delivered from 3 different points: anterior, distal right, and distal left regions. When fed anteriorly, the center line of the circumference of the virtual bite fell between the central incisors. When the force was applied from the right- and left-posterior region, the center line of the circumference of the virtual bite fell between the 5th and 6th teeth.

For the purpose of standardization, D2 bone hardness, 3mm mucosal thickness, 3.5x11mm size implants, 100% osteointegration level between bone and implant, 1mm distance between bar system and mucosa were taken in all our models. The same acrylic prosthesis was used in all models.

Microsoft Excel 10.0 and IBM SPSS software were used for statistical analysis of data. Average values (M), their standard error (m), minimum (min) and maximum (max) values of the series were determined for the received number and group indicators. Student's test and Pearson's correlation coefficient were used to test statistical hypotheses. The significance value was accepted as $p<0.05$.

RESEARCH RESULTS AND THEIR DISCUSSION

Analysis of 30 finite elements was performed on the 10 different models mentioned, from 3 different regions, with the application of 100 N masticatory force.

During the the research, the stresses related to compression and expansion in the cortical and cancellous layers of the jaw bone, the stresses on the 4 implants placed inside the jaw bone, and the stresses on the prepared bar attachment system were studied in the jaw model systems developed by us in details.

All obtained results are presented in a detailed form with figures, special graphs and pictures.

Evaluation of expansion stress indicators seen in the cortical bone layer. After applying the masticatory force in the cortical bone layer of the jaw from the anterior, right- and left-posterior regions by the finite element stress analysis method, we obtained the stress indicators related to expansion by the "Maximum Principle" rule. The highest stress value is 2.69 MPa around implant A in model 6 when force is applied from the anterior region, and around implant B in model 10 is 3.03 MPa when force is applied from the right-posterior region, and 3.14 when force is applied from the left-posterior region. It is seen around implant D in model 10 with a value of MPa. After studying the values of stress due to expansion in the cortical bone during loading from the anterior, right- and left-posterior regions, we calculated their average values for the models and divided the models into clusters using the "Cluster analysis" statistical method according to the average value of the expansion in the cortical bone. Here, models with stress values close to each other appeared in the same clusters (table 1).

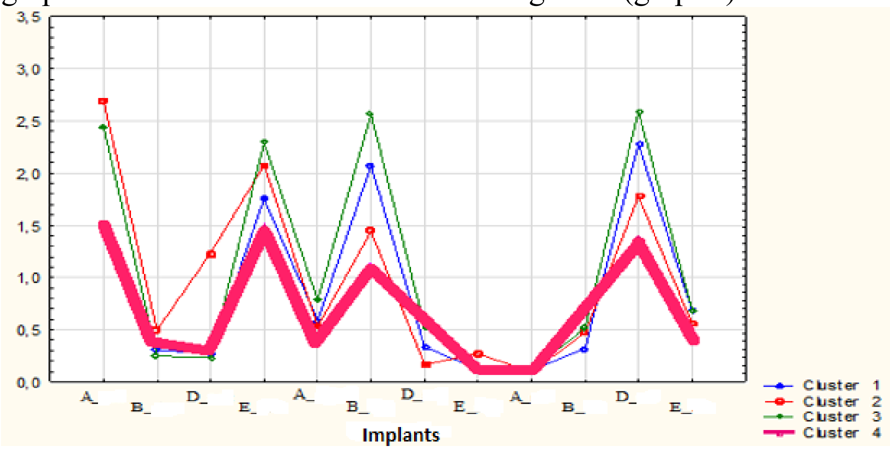
Table 1.

Average value of stress on implants in clusters from the expansion that occurs in the cortical bone during loading from the right and left posterior regions

Implants	Clusters (Models)				F	p
	Cluster1 (1,2,4)	Cluster2 (6)	Cluster3 (8,9,10)	Cluster4 (3,5,7)		
A_ant	1,50±0,311	2,69	2,44±0,181	1,52±0,101	17,17	0,0024*
B_ant	0,31±0,076	0,50	0,25±0,050	0,37±0,125	2,29	0,1781
D_ant	0,27±0,070	1,23	0,24±0,048	0,31±0,077	63,63	0,0001*
E_ant	1,76±0,129	2,08	2,29±0,059	1,50±0,240	13,34	0,0046*
A_right	0,59±0,037	0,53	0,78±0,426	0,40±0,112	1,12	0,4134
B_right	2,07±0,169	1,44	2,56±0,409	1,13±0,242	13,36	0,0046*
D_right	0,33±0,085	0,17	0,53±0,227	0,63±0,085	3,53	0,0884
E_right	0,12±0,029	0,27	0,09±0,021	0,12±0,010	17,10	0,0024*
A_left	0,11±0,012	0,09	0,10±0,025	0,10±0,013	0,34	0,7951
B_left	0,32±0,034	0,47	0,52±0,205	0,69±0,031	4,77	0,0496*
D_left	2,28±0,098	1,78	2,59±0,476	1,37±0,627	3,95	0,0719
E_left	0,69±0,161	0,56	0,69±0,563	0,41±0,173	0,42	0,7442

Note: * - the difference is statistically significant (Fisher's F Test)

To better understand the comparison of the obtained values, we expressed the average values for each cluster in the form of a linear graph and different colors in the following form (graph 1).



Graph 1. Variation of the compression generated in cortical bone during loading from anterior, right and left posterior regions by implants in clusters (average value)

If we give attention to the purple line in graph 1, we can see that it undulates more smoothly than the other lines, there are no sharp peaks of descent and ascent. In short, the given stress is more optimally distributed in cluster 4 related to this line. If we look at previous Table 1, we will see that the 3rd, 5th and 7th models have come together in cluster 4. It means he stress generated by the masticatory force falling on these models is more optimally distributed in the cortical bone.

Evaluation of compression stress indicators seen in the cortical bone layer. After applying force in the specified regions, we studied the compression stress values in the cortical bone layer of the jaw by the "Minimum Principle" rule using the finite element stress analysis method. Looking at the obtained results, the highest stress values are -3.84 MPa around implant B in model 6 when the masticatory force is applied from the anterior region, and -9.65 MPa when applied from the right-posterior region -9.65 MPa around implant A in Model 10, when applied from the left-posterior side and -9.99 MPa was detected around implant E in model 10. After studying the compressive stress values generated in the cortical bone during loading from the anterior, right- and left-posterior regions using the finite element analysis method, we calculated the average values for the models and divided the models into clusters by the "Cluster analysis" method according to the average value of the compression generated in the cortical bone. Here, the models with stress values close to each other appeared in the same clusters (table 2).

For better understanding the comparison of the obtained values, we again expressed the average values for each cluster in the form of a linear graph and different colors in the following form (graph 2).

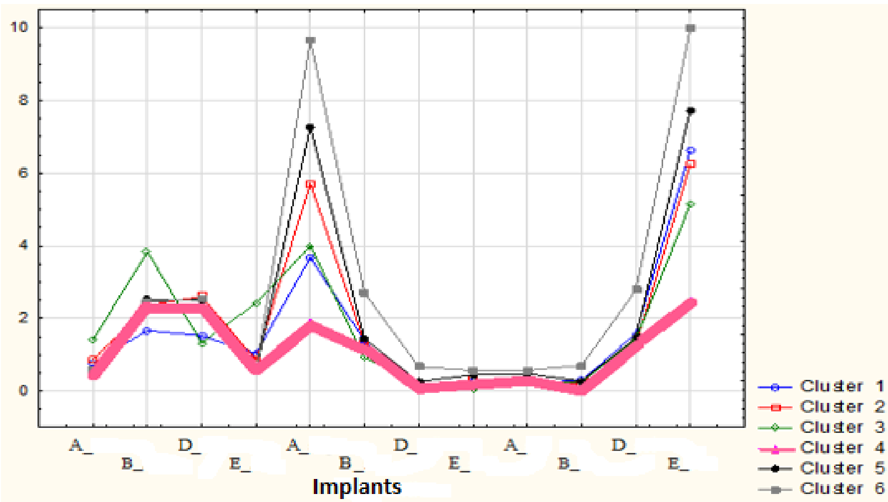
If we look at the purple line among the different colored lines that fluctuate in graph 2, we can see that it undulates more smoothly compared to the other lines. There are no sharp descent or ascent points.

It suggests that stress is more optimally distributed in cluster 4, which belongs to the purple line.

Table 2.
Average value of stress on implants by clusters from the compression generated in cortical bone during loading from the anterior, right and left posterior regions (M±SD)

Implants	Clusters (Models)						F	p
	Cluster1 (4)	Cluster2 (1,2)	Cluster3 (6)	Cluster4 (3,5,7)	Cluster5 (8,9)	(10)		
A_ant	0,76	0,86±0,001	1,41	0,46±0,037	0,57±0,032	0,60	164,7	0,0001*
B_ant	1,67	2,37±0,003	3,84	2,40±0,084	2,52±0,079	2,46	99,6	0,0003*
D_ant	1,53	2,61±0,004	1,33	2,37±0,233	2,49±0,042	2,54	13,5	0,0130*
E_ant	1,04	0,86±0,003	2,42	0,55±0,034	0,59±0,002	0,60	1015,0	0,0000*
A_right	3,67	5,71±0,019	3,99	1,92±0,318	7,27±0,793	9,65	61,7	0,0007*
B_right	1,39	1,33±0,009	0,92	1,14±0,121	1,43±0,012	2,70	58,1	0,0008*
D_right	0,17	0,19±0,002	0,22	0,09±0,030	0,26±0,002	0,67	118,4	0,0002*
E_right	0,26	0,29±0,021	0,05	0,20±0,084	0,45±0,004	0,57	11,8	0,0166*
A_left	0,23	0,28±0,002	0,23	0,20±0,068	0,48±0,046	0,57	12,4	0,0152*
B_left	0,29	0,22±0,001	0,26	0,06±0,008	0,28±0,001	0,70	2146,6	0,0001*
D_left	1,59	1,28±0,003	1,42	1,23±0,319	1,49±0,025	2,78	7,7	0,0349*
E_left	6,62	6,25±0,009	5,15	2,51±0,295	7,74±0,054	9,99	266,5	0,0003*

Note: * - the difference is statistically significant (Fisher's F-test)



Graph 2. Variation of the compression generated in cortical bone during loading from anterior, right and left posterior regions by implants in clusters (average value)

If we give attention to cluster 4 in table 2, we will see that models 3, 5, and 7 came together here. In short, the stress generated in the cortical bone during chewing have been distributed more optimally in these models.

Evaluation of the stress indicators related to the expansion seen in the cancelluos bone layer. After applying the masticatory force in the cancelluos bone layer, which is another layer of the jaw, from the anterior, right- and left-posterior regions, we determined the stress values related to expansion by the "Maximum Principle" rule. The highest observed stress value was 0.93 MPa around in model 6when the masticatory force was applied from the anterior region, 1,35 MPa around implant A in model 9 when applied from the right-posterior region and 1.76 MPa around implant E in model 1 and 2 when applied from the left-posterior region. After studying the stress values related to the expansion of cancelluos bone during loading from the anterior, right- and left-posterior regions by finite element analysis, we calculated their average values on the models, and according to the average value of the expansion of cancelluos bone, we divided the models into clusters using the statistical method "Cluster analysis". Here also, the models with stress values close to each other found their place in the same clusters (table 3).

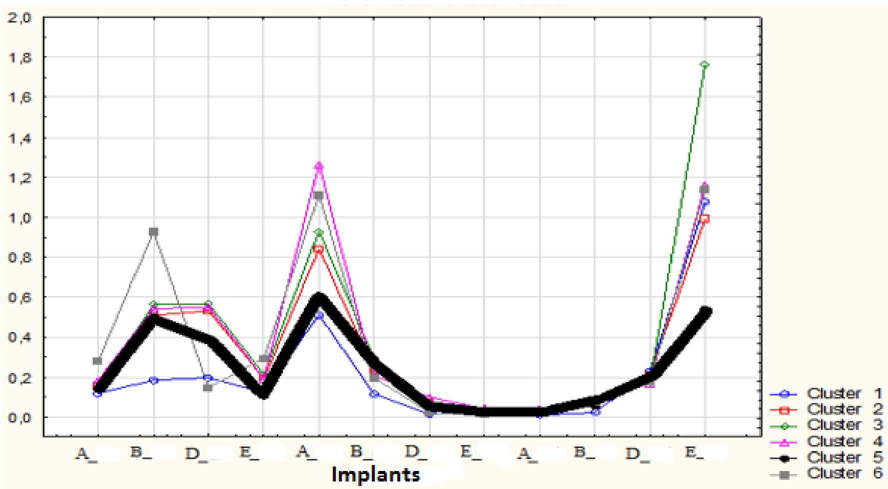
In order to better understand the comparison, we expressed the average values for each cluster in the form of a line graph and different colors as following (graph 3).

Looking at the change in the expansion of cancelluos bone during loading from different regions by implants in clusters in graph 3, we see that the fluctuation of the black line expressing cluster 5 is smoother in comparison with other lines. This allows us to say that the distribution of stress in models belonging to cluster 5 during chewing movements is more optimal in relation to other models.

Table 3.
Average value of stress on implants by clusters from the compression generated in cancelluos bone during loading from the anterior, right and left posterior regions (M±SD)

Implants	Clusters (Models)						F	p
	Cluster1 (4)	Cluster2 (3,8)	Cluster3 (1,2)	Cluster4 (9,10)	Cluster5 (5,7)	Cluster6 (6)		
A_ant	0,120	0,159±0,008	0,139±0,000	0,185±0,049	0,139±0,008	0,279	5,9	0,0551
B_ant	0,185	0,510±0,039	0,564±0,001	0,542±0,034	0,501±0,009	0,928	81,3	0,0004*
D_ant	0,198	0,532±0,018	0,569±0,001	0,551±0,045	0,388±0,127	0,149	9,7	0,0235*
E_ant	0,123	0,191±0,027	0,212±0,000	0,194±0,088	0,106±0,027	0,294	2,6	0,1878
A_right	0,510	0,840±0,146	0,929±0,004	1,261±0,126	0,610±0,027	1,110	13,3	0,0132*
B_right	0,116	0,238±0,078	0,293±0,051	0,209±0,029	0,258±0,007	0,199	2,0	0,2543
D_right	0,015	0,075±0,016	0,069±0,000	0,100±0,024	0,057±0,012	0,022	5,9	0,0554
E_right	0,023	0,023±0,012	0,027±0,000	0,043±0,014	0,027±0,018	0,015	0,80	0,6039
A_left	0,010	0,024±0,001	0,019±0,000	0,039±0,019	0,021±0,002	0,026	1,5	0,3559
B_left	0,023	0,072±0,009	0,073±0,000	0,093±0,034	0,058±0,004	0,078	2,4	0,2136
D_left	0,226	0,210±0,112	0,173±0,060	0,169±0,061	0,216±0,040	0,177	0,18	0,9554
E_left	1,075	0,993±0,115	1,765±0,000	1,160±0,017	0,540±0,149	1,140	34,6	0,0022*

Note: * - the difference is statistically significant (Fisher's F-test)



Graph 3. Variation of the compression generated in cancelluos bone during loading from anterior, right and left posterior regions by implants in clusters (average value)

Evaluation of the compression related stress indicators seen in the cancelluos bone layer. We also obtained compression stress results in cancelluos bone layer using the "Minimum Principle" rule by the finite element analysis method. If we review the results we have obtained, the highest stress value is 0.46 MPa around implant B in model 6 when the masticatory force is given from the anterior region, 1.22 MPa around implant A in model 10 when given from the right-posterior region and around implant B in model 6 and 0.99 MPa around implant E in model E when given given from the posterior region. Then, after studying the compressive stress values in cancelluos bone using finite element analysis method, we calculated their average values for the models and according to the average value of cancellous bone compression, we divided the models into clusters using the "Cluster analysis" statistical method. The models with closer stress values gathered together in the clusters (table 4).

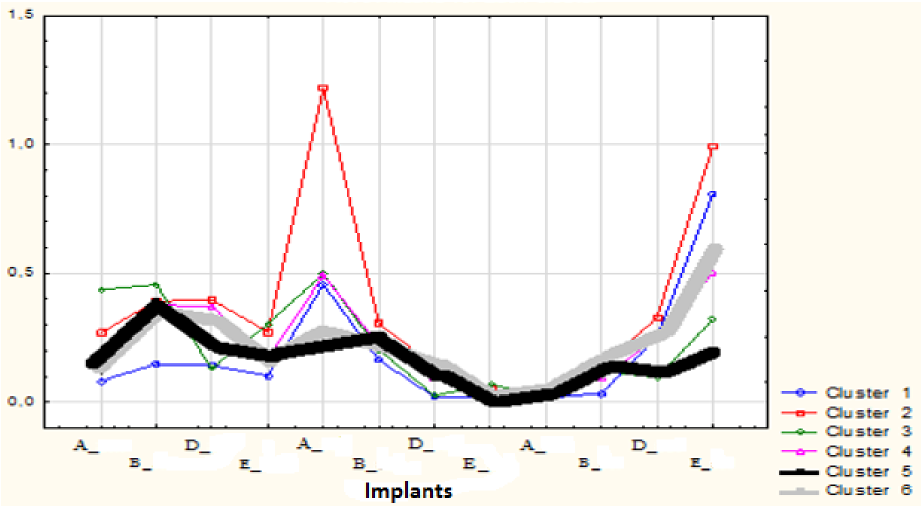
Table 4.

Average value of stress on implants by clusters from the compression generated in cancelluos bone during loading from the anterior, right and left posterior regions (M±SD)

Implants	Clusters (Models)						F	p
	Cluster1 (4)	Cluster2 (10)	Cluster3 (6)	Cluster4 (1,2,8,9)	Cluster5 (7)	Cluster6 (3,5)		
A_ant	0,083	0,271	0,437	0,145±0,016	0,122	0,132±0,013	78,9	0,0004*
B_ant	0,149	0,393	0,457	0,378± 0,024	0,392	0,369± 0,013	23,6	0,0046*
D_ant	0,142	0,398	0,132	0,373± 0,060	0,232	0,325± 0,049	5,4	0,0637
E_ant	0,103	0,273	0,305	0,167± 0,029	0,172	0,160± 0,001	9,8	0,0232*
A_right	0,457	1,217	0,499	0,492± 0,071	0,214	0,287± 0,103	21,6	0,0054*
B_right	0,164	0,307	0,204	0,225± 0,032	0,255	0,242± 0,049	1,8	0,3036
D_right	0,021	0,137	0,025	0,096± 0,001	0,133	0,146± 0,016	61,5	0,0007*
E_right	0,021	0,054	0,071	0,023± 0,003	0,018	0,026± 0,016	8,1	0,0324
A_left	0,018	0,046	0,023	0,020± 0,003	0,027	0,023± 0,006	7,8	0,0347*
B_left	0,035	0,137	0,121	0,095± 0,005	0,146	0,153± 0,022	18,5	0,0072*
D_left	0,255	0,330	0,096	0,254± 0,062	0,125	0,260± 0,014	2,9	0,1601
E_left	0,808	0,991	0,322	0,502± 0,066	0,182	0,597± 0,005	28,3	0,0032*

Note: * - the difference is statistically significant (Fisher's F-test)

To make clear the comparison of the values we have obtained, we expressed the average values for each cluster in the form of a linear graph and different colors as following (graph 4).



Graph 4. Variation of the compression generated in cancelluos bone during loading from anterior, right and left posterior regions by implants in clusters (average value)

When we look at the change of compression in cancelluos bone by implants in the clusters in graph 4 after loading from different regions, we observe that the wavy continuation of the black and gray lines representing clusters 5 and 6 is smoother compared to other lines, that is, there are no sharp descent and ascent peaks. This enables us to say that stress distribution in models 3, 5, 7 belonging to clusters 5 and 6 during chewing movements is more optimal than other models.

Evaluation of the stress indicators seen on the implants. We have studied the stresses on implants, another parameter by the finite element method, through the “Von Misses” rule. After applying the masticatory force from the anterior, right - and left-posterior regions, the highest stresses were observed in the anterior loading model 8 with 19.91 MPa on implant A, in the right-posterior loading model 8 with 103.98 MPa on implant A, and in the left-posterior loading Model 9 with 104.68 MPa on implant E. Although the stress indicator on implant A was very high, 43.21 MPa at the stage of applying the masticatory force from the posterior-right region of the implantable prosthesis of model 1 of the study, but the pressures on implants B, D, and E were 5.99 MPa, 2.04 MPa, and 0.73 MPa, respectively.

At the stage of determining the stress indicators that generated in the implants during the loading of the implantable structure of the model 9 system with the masticatory forces from the anterior region, in the chapter which includes the details, materials and methods of the study, the stress level of implant E demonstrated the maximum indicator of 19.77 MPa. From this point of view, the E implant was followed by the A implant, so that the pressure created in it under the influence of masticatory force was 17.98 MPa. At this stage, the stress indicators observed in the B and D implants of the model-9 system were manifested as 11.03 MPa and 11.73 MPa, respectively.

During the study, the maximum stress level during mastiicator force loading of the Model 9 system from the rear-right region was 95.94 MPa, followed by an implant. The stress indicators observed in implants B,D and E of the system, respectively, were 6.01 MPa, 2.13 MPa and 1.88 MPa, which were significantly lower than the analogous indicators of implant A.

After studying the stress values on implants during loading from the Anterior, right - and left-posterior regions by the finite element analysis method, we calculated their average values on the models and divided the models into clusters by the statistical method “Cluster analysis” according to the average value of the stress on the implants. Here, models with stress values close to each other showed themselves in the same clusters (table 5).

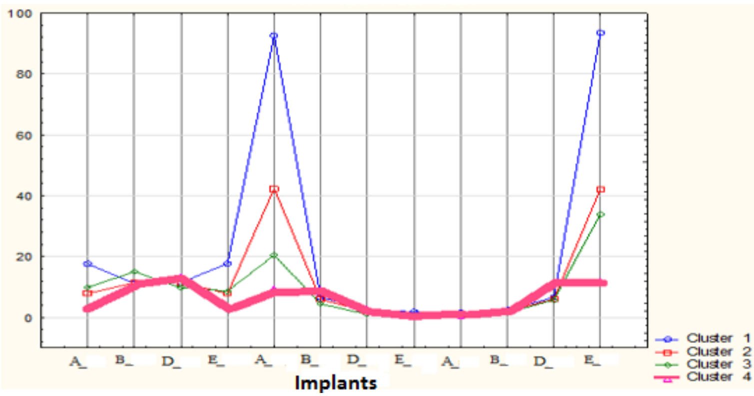
To make the comparison of the resuts we have obtained more clear, we indicated again expressed the average values for each cluster in the form of a linear graph and different colors in the following form (graph 5). If we look at the purple line among the different colored lines that fluctuate in graph 2, we can see that it undulates more smoothly compared to the other lines. There are no sharp descent or ascent points.

Table 5.
Average value of stress on implants by clusters from the during loading from the anterior, right and left posterior regions(M±SD)

Implants	Clusters (Models)				F	p
	Cluster1 (8,9,10)	Cluster2 (1,2)	Cluster3 (4,6)	Cluster4 (3,5,7)		
A_ant	17,7±2,41	7,9±0,18	10,0±8,47	3,4±0,36	7,5	0,0184*
B_ant	11,1±0,26	11,5±0,43	15,0±3,76	10,7±3,14	1,5	0,3047
D_ant	11,5±0,18	11,7±0,09	9,8±4,41	13,5±3,61	0,75	0,5591
E_ant	17,7±1,80	7,9±0,08	8,7±4,75	3,2±0,59	22,0	0,0012*
A_right	92,7±13,27	42,3±1,21	20,5±3,74	9,4±4,90	56,7	0,0001*
B_right	6,7±1,04	5,9±0,12	4,5±1,93	9,2±3,24	2,2	0,1924
D_right	2,5±0,58	2,0±0,01	1,04±0,61	2,8±0,81	3,5	0,0905
E_right	1,9±0,14	0,74±0,016	0,76±0,293	0,52±0,045	50,9	0,0001*
A_left	1,8±0,29	0,75±0,013	0,76±0,301	0,60±0,041	18,8	0,0019*
B_left	2,5±0,59	2,0±0,00	1,6±0,29	2,3±0,73	1,2	0,3792
D_left	6,6±1,02	6,1±0,12	5,8±1,24	11,4±5,15	2,0	0,2157
E_left	93,5±11,07	42,2±0,53	33,9±10,73	12,1±3,26	55,1	0,0001*

Note: * - the difference is statistically significant (Fisher's F-test)

When we look at graph 5, we see that the purple line expressing cluster 4 wave more smoothly in comparison with other lines representing other clusters. There are no sharp descent and ascent peaks compared to other lines. This enables us to say that implant stress distribution in models 3, 5, 7 gathering together in cluster is more optimal than other models.



Graph 5. Variation of the implant stresses during loading from anterior, right and left posterior regions by implants in clusters (average value)

Evaluation of the stress indicators seen in the bar attachment We also examined the stresses on the bar atachment system, another parameter of our study through method of finite elements analysis. After applying force from different directions, the highest stress values on the bar atachment system were found in the anterior loading Model 9 with 30.84 MPa in the A implant region, in the right-posterior loading Model 9 with 158.31 MPa in the A implant region, and in the left-posterior loading model 9 with 131.34 MPa in the E implant region. At this stage of the research, the stress indicator on the bar atachment region on the implant A was 13.34 MPa when the anterior region of the Model 1 system implant was affected by masticotary force. At this stage of the study, the stress indicators that occurred in other regions of the implantable atachment bar system under the influence of masticotary force from the appropriate direction were almost equal. Thus, the stress indicators in the regions of atachment bar system on B, D and E implants were 13.82 MPa, 14.37 MPa and 11.34 MPa respectively.

At the stage of the study, when we studied the stress indicators of the implant structure of the model 6 system, which occur in the implant-compatible regions of the bar atachment system during masticatory force loading from the anterior region, the maximum indicator was 20.09 MPa, which corresponded to the atachment region on the implant B of the system. The atachment region corresponding to implant B of the system was followed by the atachment region corresponding to implant A, the analogous indicator of which was 15.03 MPa. In this case, the stress indicators that appeared in the atachment regions corresponding to the D and E implants of the system showed very slight differences. Thus, in accordance with the stress indicators observed in the mentioned regions, 10.22 MPa and 11.77 MPa were found.

The maximum atachment region stress occurred on implant A at the stage of the Model 6 system of the study, which was loaded with masticatory force from the right-posterior region, 16.94 MPa. At this time, the stress indicators occurring in the atachment regions on the B, D and E implants of the system were sequentially manifested as 3.13 MPa, 1.02 MPa and 0.96 MPa.

As a result of the study, the maximum atachment region stress when loaded with masticatory force on the left-posterior region of the Model 6 system implant was recorded on the E implant located on the far left of the system, 26.53 MPa. During this period of the study, the minimal atachment Stress Indicator was recorded on implant A, 0.93 MPa. With a significant difference between the stress indicators in the atachment regions on the B and D implants of the Model 6 system, 1.65 MPa and 9.77 MPa were sequentially determined. At the stage of the study, where we determined the stress indicators of the implantable bar atachment regions during the application of masticatory forces from 3 directions, apart from the anterior, left-posterior and right-posterior regions of the Model 8 system, the minimum indicator obtained was 2.37 MPa in the region of the Atachment on the D implant during loading of the system from the right-posterior region, and the maximum indicator was 147.81

At the stage of the study in which we studied the stress levels occurring in the regions of the implantable bar atachment during the loading of the implantable prosthesis from the anterior region of the model 9 system by masticatory force, the maximum indicator was recorded in the region of the bar atachment on implant A, 30.84 MPa. In this regard, the stress indicator of the bar atachment region on the A implant followed by the bar atachment region on implant E, 25,92 MPa. At this stage of research, the stress indicators on the bar atachment regions on the B and D implants of the model 9 system were found to be 13.85 MPa and 14.30 MPa, respectively.

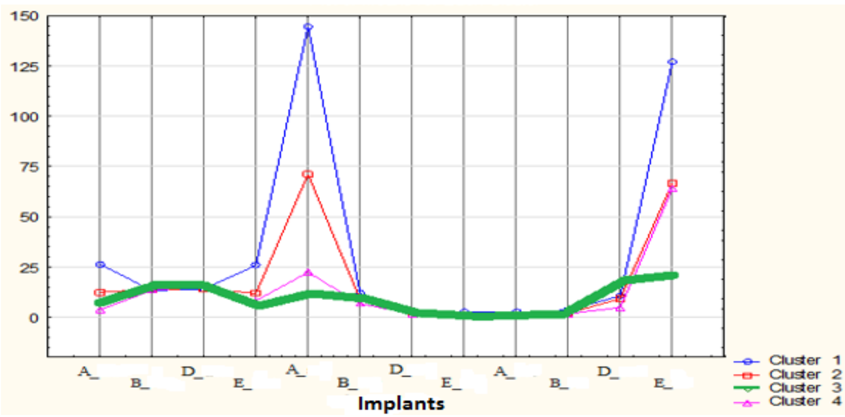
After studying the stress values arising on the post - loading bar atachment system from the Anterior, right-and left-posterior regions by the finite element analysis method, we calculated the average values for the models and divided the models into clusters by the statistical method “Cluster analysis” according to the average value of the stress seen on the implants. Here also the models with closely spaced stress values found a place in the same clusters (table 6).

Table 6.
Average value of stress on the bar atachment system during loading from the Anterior, right and left posterior regions on implants in clusters (M±SD)

Implants	Clusters (Models)				F	p
	Cluster1 (8,9,10)	Cluster2 (1,2)	Cluster3 (3,5,6,7)	Cluster4 (4)		
A_ant	26,4±3,86	12,4±1,28	6,6±5,64	3,7	12,4	0,0055*
B_ant	13,3±1,37	13,8±0,01	14,1±5,13	13,3	0,03	0,9918
D_ant	14,1±0,25	14,2±0,21	16,1±7,92	15,5	0,09	0,9620
E_ant	25,8±0,97	11,8±0,71	6,0±3,87	8,3	30,1	0,0005*
A_right	144,5±15,67	71,1±8,01	12,1±5,24	22,3	100,7	0,0000*
B_right	11,9±5,11	9,0±0,44	10,2±6,94	6,7	0,24	0,8672
D_right	2,7±0,63	2,2±0,04	3,1±2,04	1,6	0,38	0,7729
E_right	2,6±0,28	1,1±0,09	0,82±0,32	0,72	25,2	0,0008*
A_left	2,5±0,53	1,2±0,07	0,72±0,15	0,49	20,6	0,0015*
B_left	3,5±2,13	2,1±0,01	2,5±0,95	1,7	0,68	0,5980
D_left	10,6±1,89	9,1±0,77	17,8±12,76	4,8	0,83	0,5232
E_left	127,0±6,21	66,8±4,21	21,1±6,78	64,0	165,1	0,0000*

Note: * - the difference is statistically significant (Fisher's F-test)

To make the comparison of the resuts we have obtained more clear, we indicated expressed the average values for each cluster in the form of a linear graph and different colors in the following form (graph 6).



Graph 6. Variation of the implant stresses during loading from anterior, right and left posterior regions by implants in clusters (average value)

When you give attention to graph 6, the green line denoting cluster 3 waves smoother in comparison with the lines denoting other casters. There are no sharp descent or ascent points relative to other lines. That is, in 3,5,7 models, which come togerther in cluster 3, the distribution of stresses on implants was more optimal in comparison with other models.

After carrying out the analysis and comparison of the obtained indicators, the most optimal stress distribution was observed in models with an implant location level of 3 mm. Also in the model with a cantilever protrusion of 0 mm, the optimal stress distribution was recorded. And the amount of stress recorded in models with a location level of 1 mm showed that a leveling process may be necessary in the jaws corresponding to that bone topography. Due to the uneven distribution of stress indicators that we get in models placed at an angle, and the rather high amount of stress indicators falling on implants, it is necessary to avoid placing implants at an angle whenever possible.

Thus, according to the research we conducted on models based on the 3D finite elements stress analysis method, we can conclude that the distribution of stresses in the 3rd model without a cantilever is optimal. In models with an implant level of 3 mm, i.e. models 5 and 7, we may not make additional changes to the bone with a jaw corresponding to this configuration during implant surgery, as the stresses arising on the bar system are more optimally distributed. The forces such as expansion and compression that occur on the bone-implant intermediate surface have a significant impact on the quality and continuity of osteointegration. For example, the force of expansion, which has an effect on bone tissue, weakens the density of the bone. Therefore, when designing the structure of implants, the ratio and balance of the above-mentioned forces should be taken into account.

CONCLUSION

1. After applying masticatory force from different regions in the cortical bone layer of the jaw through finite elements stress

analysis method, expansion stress indicators were seen with the highest stress value 2.69 MPa around implant A in model 6 when applying force from anterior region, 3.03 MPa around implant B in Model 10 when applying force from right-posterior region, and 3.1 MPa around implant D in model 10 when exerting force from left-posterior region. The highest compression stress indicators were found with stress value -3.84 MPa around implant B in Model 6 MPa when masticatory force was applied from anterior region, with stress value -9.65 MPa around implant A in model 10 when masticatory force was applied from right-posterior region, and with stress value -9.99 MPa around implant E in Model 10 when masticatory force was applied from left-posterior region. Analysis of stress outcomes on both expansion and compression in the cortical layer showed that stress distribution was more optimal in our 3,5,7 models [1,2,4,8,9].

2. After applying masticatory force from anterior, right - and left-posterior regions in cancelluos bone layer of jaw through finite elements stress analysis method, the highest expansion stress indicators were around implant B with 0.93 MPa in Model 6 when applying masticatory force from anterior region, around implant A with 1.35 MPa in Model 9 when applying masticatory force from right- posterior region and around implant E with 1.76 MPa when applying from left- posterior region. The highest compression-related stress indicators were found around implant B in Model 6 with -0.46 MPa when masticatory force was applied from anterior region, around implant A in Model 10 with -1.22 MPa when applied from right-posterior region, and around implant E in Model 10 with -0.99 MPa when applied from left-posterior region. The analysis of the results obtained in the cancelluos layer showed that the distribution of stresses in our 3,5,7 models was more optimal in comparison with other models [2,3,4,8].
3. The study of the stresses on the implants in our different models by the finite element stress analysis method revealed

that after applying the masticatory force from the anterior, right - and left-posterior regions, the highest stress value was 19.91 MPa on implant A in model 8 with anterior loading, 103.98 MPa on implant A in model 8 with right-posterior loading and 104.68 MPa on implant A in model 9 with left-posterior loading. Based on the analysis of the results obtained, we can say that in models 3,5,7, the stress caused by the masticatory force is more optimally distributed over the implants [5,6,7,8].

4. After applying force from diferent directions through finite elements stress analysis method, the highest stress values on the bar attachment system found in anterior loading Model 9 with 30.84 MPa in the A implant region, in right-posterior loading Model 9 with 158.31 MPa in the A implant region, and in left-posterior loading Model 9 with 131.34 MPa in the E implant region. Analysis of the results shows that the distribution of stresses created by the masticatory forces on the bar atachment system is more optimal in models 3,5,7 [3,4,5,7].

PRACTICAL RECOMMENDATIONS

1. Since it was revealed that the stresses generated in the models with a placement level of 3 mm are more optimally distributed, if a jaw corresponding to this configuration appears during the implantation operation, corrections may not be made by additional cutting of the bone.
2. During our research, as it was observed that the stresses generated in models with an implant placement level of 1 mm were unevenly distributed, so when a jaw corresponding to this configuration appears before us during the dental implantation operation, the process of smoothing the bone should be performed.
3. As we have observed that angled implants are under a lot of stress, it is necessary to avoid placement of implants under angel within the limits of clinical conditions.

List of published scientific paper on the

topic of the dissertation

1. Mahmudov V.S. Stresses in peri-implant mucosal layers during the use of removable implant prostheses // Modern Achievements of Azerbaijan Medicine. No. 3, 2022, ISSN 2073-2651, p. 144-150.
2. Panahov N.A., Mahmudov V.S. Application of finite element stress analysis method in dentistry // Health, No. 6, 2020 ISSN 2706-6614, p. 205-209.
3. Panahov N.A., Mahmudov V.S. Stresses in the cortical bone during the use of over-implant prostheses // Modern Achievements of Azerbaijan Medicine. No. 4, 2021 ISSN 2073-2651, p. 150-156.
4. Mahmudov V.S. Spongy expansion stress recorded around the implants during loading of the over-implant prosthesis structure // Health, No. 1, 2022, ISSN 2706-6614, p. 149-154.
5. Mahmudov V.S. Stresses generated in the implant during the use of over-implant prostheses. "XXIV Republican Scientific Conference of Doctoral Students and Young Researchers" dedicated to the 880th anniversary of Nizami Ganjavi, Baku, November 23-24, 2021. p.47-49.
6. Panakhov N.A., Mamedov F.Y., Makhmudov V.S. Finite element method for studying stresses in the implant and its surrounding bone in improving the quality of treatment of complete edentia, //Suchasna Dentistry, 3-4 (111) 2022. ISSN 1992-576, p. 56-62.
7. Panakhov N.A., Makhmudov V.S. Analysis of stress during fixation of removable dentures on implants // Current problems of modern medicine. Volume 21 Issue 4 (76) Poltava, 2021, ISSN 2077-1096, p. 121-129.
8. Mahmudov V.S. Analysis of the impact of implant prosthetics on the implant and peripheral tissues on various models, Practice Oreintead Science // UAE-Russia İndia. Materials of international University Forum Date; 12May UAE 2022. p. 161-163.
9.Makhmudov V.S. Stresses in the tissues around the implant during the application of implantable structures // international scientific-practical conference on "contemporary medicine: innovations and

modern approaches" dedicated to the 100th anniversary of Heydar Aliyev. Baku, 2023 . p. 34-35.

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