Available online at www.medicinescience.org

ORIGINAL ARTICLE

Medicine Science International Medical Journal

Medicine Science 2023;12(4):1263-8

Evaluation of the stress distributions of the treatment options with 2 implants for 4 missing maxillary incisors with finite element analysis

Hilal Siriner Gumus

Private Dental Clinic, İstanbul, Türkiye

Received 21 August 2023; Accepted 27 September 2023
Available online 19.10.2023 with doi: 10.5455/medscience.2023.08.126

Abstract

The aim of this study is to evaluate the stress distributions in the bone level, implant and prosthesis parts with three-dimensional (3D) finite element analysis (FEA) in treatment options obtained by using two implants in different positions and different diameters in the four missing maxillary incisors region. Four 3D FEA models were obtained simulating the human maxilla with anterior 4 missing teeth. It is an in vitro study evaluated only by performing FEA with a computer program. Model 1 (M1): 4.3mm diameter implant to 2 central incisors regions, Model 2 (M2): 4.3mm diameter implant to 2 lateral incisors regions, Model 3 (M3): 3.3mm diameter implant to 2 lateral incisors regions and Model 4 (M4): 4.3mm diameter implant to central incisor region, 3.3mm diameter to lateral incisor region. Titanium implants and titanium abutments were used. Four-unit monolithic zirconia cemented fixed partial prostheses were designed on them. An oblique force of 100N was applied to the cingulum of each tooth on the prosthesis at an angle of 45 degrees to the long axis. The data obtained by performing FEA on the stress values in the implants, prosthesis parts and bone were evaluated. Maximum and minimum principal stress in the bone tissue was observed most in model 3 and least in model 1. Von Mises values in the abutment, implant, screw and prosthesis were highest in model 3. According to the obtained stress values, it may be considered the best option to place a standard diameter implant where the central incisors are in the anterior region in order to reduce the stress on the bone. Treatment with a narrow-diameter implant with lateral incisors can be avoided.

Keywords: Dental implant, finite element analysis, incisors

Introduction

The maxillary anterior region is a highly aesthetically demanding region where a minor failure can compromise patients' expectations and approval [1,2]. Restoration of missing maxillary incisors is a complex and delicate treatment [3,4]. Appropriate treatment planning is very important [4-6], when using implant therapy, as choosing the appropriate number, location, and size of implants is a difficult task [7]. Implant rehabilitation is a common [8-11] and safe treatment. However, it can sometimes be limited by the patient's anatomy such as sinus pneumatization or alveolar resorption [12] in atrophic maxilla. Sometimes the bone in the atrophic maxilla is not sufficient for standard length implant placement [13]. Exceeding the physiological tolerance limits of mechanical stress can lead to restoration failure, implant fracture, screw loosening or loss of osseointegration. One of the reasons for the failure of maxillary implant treatment is such biomechanical complications of restoration and dental implants. Parameters such as bone type, position and angle of the implant, design of the implant (implant-abutment connection), magnitude and direction of the occlusal load can affect the stress/strain distribution [14-16]. Standard diameter implants have proven high success rates in long-term studies. However, in cases where the intraosseous diameter is small, narrow diameter implants are an alternative to standard diameter implants, especially in the presence of limited space with adjacent teeth [17,18].

There are many options for implant treatment applied in the absence of 4 maxillary anterior teeth. There are treatment approaches with 4 implants applied to each tooth, applied only

CITATION
Siriner Gumus H. Evaluation of the stress distributions of the treatment options with 2 implants for 4 missing maxillary incisors with finite element analysis. Med Science. 2023;12(4):1263-8.

OPEN ACCESS

Corresponding Author: Hilal Siriner Gumus, Private Dental Clinic, İstanbul, Türkiye
Email: hilalsiriner@hotmail.com

DOI: 10.5455/medscience.2023.08.126

to the central teeth, applied only to the lateral teeth, or applied to central and lateral tooth with 2 implant treatment approaches. Each of these options has advantages and disadvantages. The condition of the bone, aesthetic expectation and cost are the criteria to be considered when deciding on the treatment [5].

Although how mechanical loading affects osteoblastic and osteoclastic activities has not been fully determined. It has been suggested that variables such as stress/strain are effective mechanical stimuli for bone remodeling. It can be evaluated how these variables affect, using specially developed mathematical algorithms. We can also combine it with FEA to generate quantitative numerical models for prediction of bone remodeling [19]. The FEA allowed the researchers to predict the stresses seen in otherwise inaccessible, persistent areas of the dental implant assembly, in contact areas, peri-implant bone [20], internal parts of implants and prosthetic components [21].

The FEA performs computer analysis including loading conditions and material properties. FEA has many advantages. It offers us easy model modification of the structure consisting of bone, implant and prosthesis. It represents internal stress states and mechanical quantities [22].

The aim of this study was to examine the stress distribution in the implant, prosthesis and bone tissue in the treatment options obtained by placing implants of different diameters in different positions in the anterior maxilla. The null hypothesis tested is that the location and diameter of the implant do not affect the stress on the prosthesis, implant and bone tissue.

Material and Methods

For the study, four 3D maxillary models simulating the maxilla with missing 4 anterior teeth were obtained with a computer program. This is not a study on patients, only a special computer program was used. Therefore, ethics committee approval is not required. Data were improved and transferred to SolidWorks computer-aided design (CAD) program. The maxillary arch was modeled as 19 mm height , 18 mm mesiodistal width, and a buccolingual depth of 15 mm. The model contains trabecular bone and 1mm of cortical bone covering it. Titanium conical implant (Implantswiss implant), titanium abutment (Implantswiss abutment) and 4-member cemented monolithic zirconia (Prettau, Zirkonzahn) prosthesis were used in the models. Obtained groups are shown in Table 1 and schematized in Figure 1.

Table 1. The positions and diameters of implants used in this FEA study

Groups	Implant's position	Implant's diameter
Model 1 (M1)	Central-Central	4.3mm (length 10mm)
Model 2 (M2)	Lateral-Lateral	4.3mm (length 10mm)
Model 3 (M3)	Lateral-Lateral	3.3mm (length 10mm)
Model 4 (M4)	Central-Lateral	4.3mm–3.3mm (length 10mm)

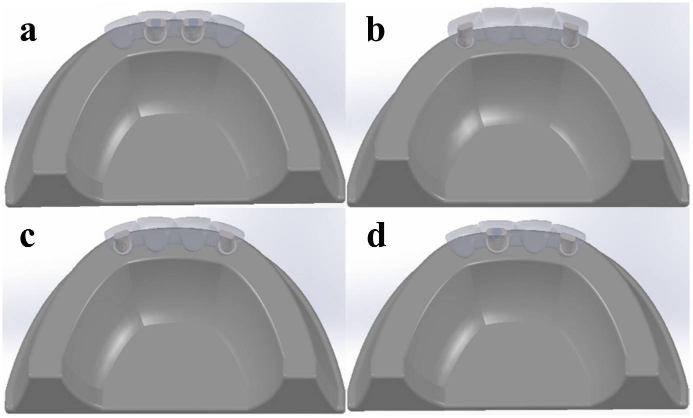

Figure 1. Drawings of the groups tested, **1a.** Model 1, **1b.** Model 2, **1c.** Model 3, **1d.** Model 4

The materials were considered isotropic, homogeneous and linear elastic. The values of Young's modulus and Poisson's ratio are explained in Table 2. An oblique force of 100N was applied to the cingulum of each tooth on the prosthesis at an angle of 45 degrees to the long axis. Evaluation was performed on Ansys software. Maximum and minimum principal stress values in bone tissue and von Mises values in implants, abutments and prosthesis were obtained.

Table 2. Material properties used in this FEA study

Materials	Modulus of elasticity (Mpa)	Poisson's ratio
Cortical bone	13.7	0.30
Cancellous bone	1.10	0.30
Titanium	110	0.34
Zirconia	210	0.33

Results

The von Mises, maximum and minimum principal stress values of the cortical bone in all groups, as well as the von Mises values of the implant, abutment, screw and prosthesis are shown in Table 3.

The minimum principal stress in the bone tissue is concentrated in the vestibule region, especially in the cervical part of the implant. Among all models, the highest minimum principal stress value was seen in model 3 and the least in model 1. Maximum principal stress is concentrated in the cervical part of the implant in the palatal region. This value was found at most in model 3 and at least in model 1 (Figure 2).

Figure 3 shows the stress intensity on the right and left implants in each group. The area of greatest stress is in the neck of the implants and on the vestibule side. While the von Mises values of the implants are similar in models 1, 2 and 4, they are higher in model 3 than the others.

When we look at the stress on the screw, we see that the highest value is in model 3. Maximum stress on screws occurs between head and shank (Figure 4).

Table 3. The values of the von Mises stresses in all models

Model	Cortical bone			Right implant	Left implant	Right abutment	Left abutment	Right screw	Left screw	Prosthesis
	von Mises	Maximum principal	Minimum principal	von Mises	von Mises	von Mises	von Mises	von Mises	von Mises	von Mises
Model 1	20.866	27.956	18.134	145.24	141.02	121.2	121.41	46.971	49.807	65.733
Model 2	24.473	32.841	19.163	197.63	192.12	200.5	201.7	40.696	45.686	80.95
Model 3	33.151	38.451	34.978	401.6	363.38	648.67	631.54	61.966	61.995	84.792
Model 4	28.192	37.263	21.63	194.64	230.7	184.35	208.61	54.642	37.261	61.465

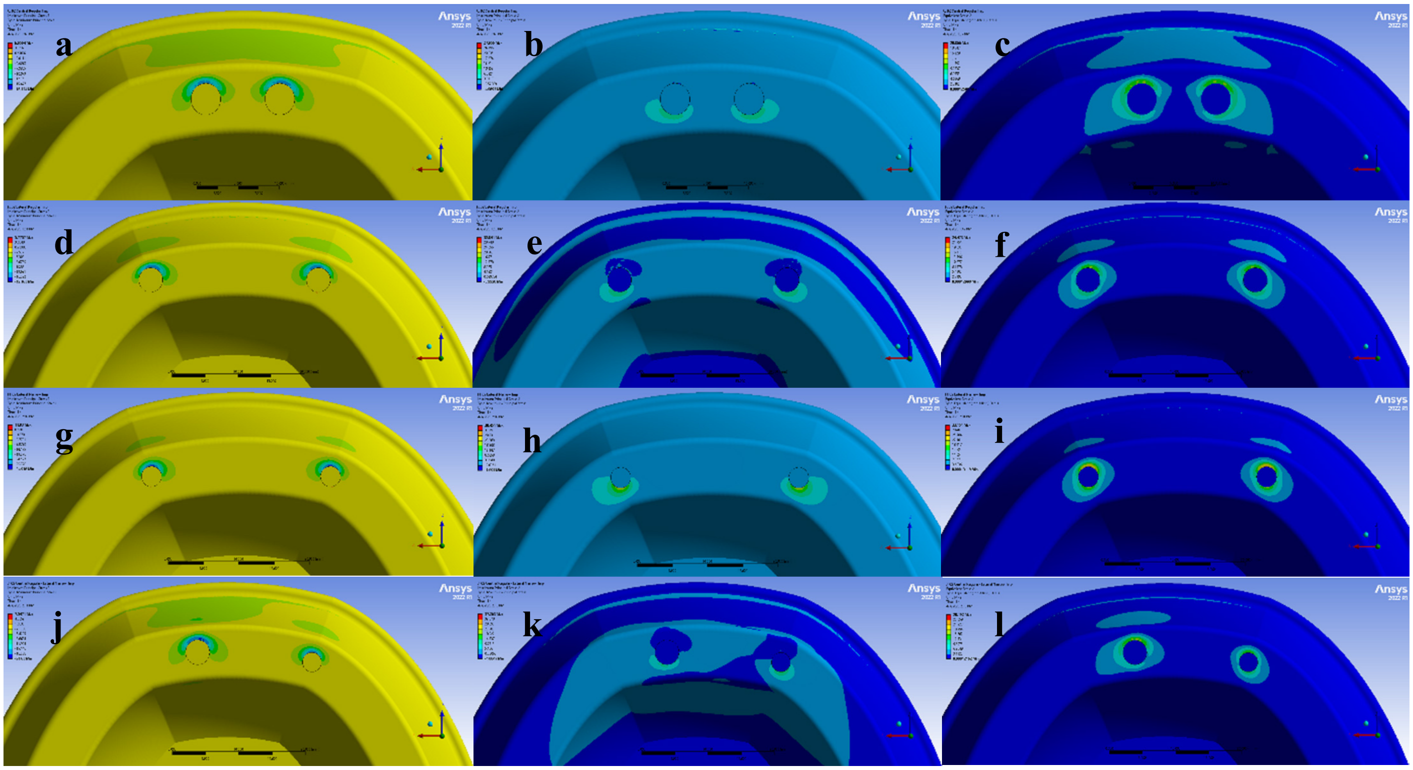

Figure 2. Distribution of the minimum principal stress on bone tissue; **2a.** Model 1, **2d.** Model 2, **2g.** Model 3, **2j.** Model 4. Distribution of the maximum principal stress on bone tissue; **2b.** Model 1, **2e.** Model 2, **2h.** Model 3, **2k.** Model 4. Distribution of the von Mises stress on bone tissue; **2c.** Model 1, **2f.** Model 2, **2i.** Model 3, **2l.** Model 4

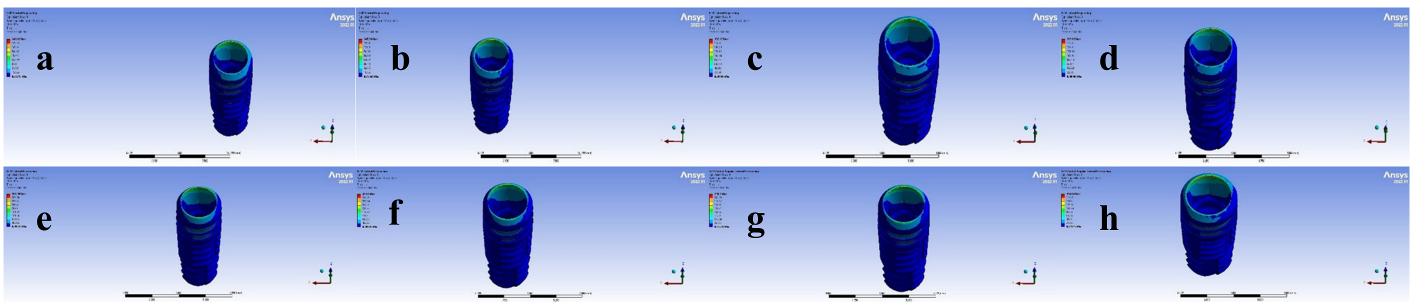

Figure 3. Distribution of the von Mises stress on left and right implants for each group, **3a.** Model 1 left, **3b.** Model 1 right, **3c.** Model 2 left, **3d.** Model 2 right, **3e.** Model 3 left, **3f.** Model 3 right, **3g.** Model 4 left, **3h.** Model 4 right

DOI: 10.5455/medscience.2023.08.126

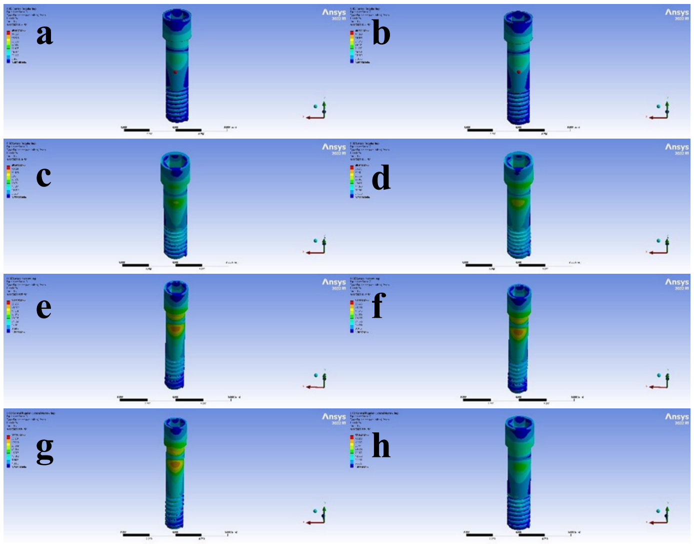

Figure 4. Distribution of the von Mises stress on left and right screws for each group, **4a.** Model 1 left, **4b.** Model 1 right, **4c.** Model 2 left, **4d.** Model 2 right, **4e.** Model 3 left, **4f.** Model 3 right, **4g.** Model 4 left, **4i.** Model 4 right

In models with the widest distance between implants, that is, in models 2 and 3, where the implants are placed on the laterals, it has been observed that the stress seen in the prosthesis is not only on the cervical part on the implant, but also on the connector parts. The highest value is again in model 3 (Figure 5).

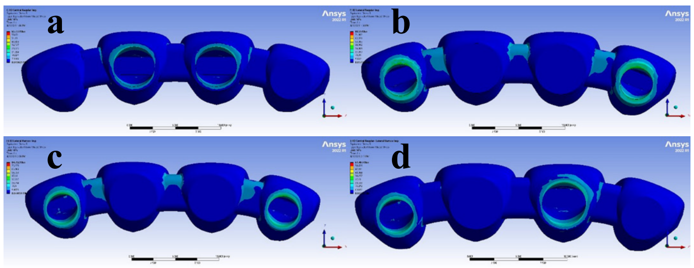

Figure 5. Distribution of the von Mises stress on prosthesis, **5a.** Model 1, **5b.** Model 2, **5c.** Model 3, **5d.** Model 4

Discussion

It is very difficult to identify the strengths and behavioral patterns of structures in living organisms such as tissues and organs in the oral cavity. In fact, this can sometimes be risky, costly or even impossible. In such cases, it is necessary to work in in-vitro models. FEA analyzes the system into small parts and gives us information about the whole. Calculates the interplay of these small parts with individual environmental effects and their interplay with each other using numerical methods [13].

Clinical relevance of FEA data is limited. Because bone tissue is orthotropic structure and anisotropic, but the structures in the FEA model are assumed to be homogeneous, isotropic and linear elastic [23].

The amount of alveolar bone, including both the alveolar shape and the bone volumes at the implant sites, is an important factor for the success of implant treatment. Therefore, it is important to properly assess both factors, bone quantity and bone quality, in any treatment plan involving implants [24]. We selected D2 type bone in the study and assumed 100% osteointegration. The higher failure rate of implants restored in the maxilla requires the clinician to be more aware of the mechanical behavior of implant-supported prosthesis in type 3 bone [8]. Since our aim was to investigate the effect of the positions of the implants, we chose D2 type bone. However, it would be useful to evaluate the effects of different types of bones in another study.

Vaidati et al. [5] evaluated the treatment options with implants for missing 4 anterior teeth in the maxilla. They also mentioned the treatment performed by applying 4 implants in the study. They mentioned the disadvantages such as the implants may be too close to each other or to the adjacent natural teeth due to the limited space, the aesthetic appearance may be insufficient due to the loss of papillae, and the high cost will be required due to the number of implants. For this reason, we evaluated the treatment options of 4 anterior tooth deficiencies with only 2 implants in our study.

In the study, we only compared the difference in diameters, keeping the length of the implants the same (10mm). Because from a biomechanical point of view, the role of implant diameter is considered to play a greater role in design than its length. Therefore, implant length does not appear to be an important factor contributing to osseointegration, since the applied stress is mainly distributed over the cortical bone rather than the remainder of the bone-implant interface [15].

In our study, implant combinations of different diameters and locations were used. Therefore, it is different that the prosthesis contains a cantilever. We kept the brand and type of implants constant in order not to increase the parameters.

While measuring the stress values, we applied a force of 100N to the prosthesis. The force was an oblique force applied to the long axis of the anterior teeth at an angle of 45 degrees. Clinical differences in chewing strength in different sexes and under different loading conditions prompted further examination of potential discrepancies. 100 N was based on the maximum reported chewing force [25]. When the teeth are in centric occlusion, the mandibular incisors are at the level of the palatal surfaces of the maxillary incisors. Therefore, applying force in the bucco-lingual direction to the cingulum region of the maxillary teeth simulates the clinical situation in studies. So we have the opportunity to evaluate the condition of the implants in the anterior maxilla [8].

Overloading of the prosthetic structure can cause stresses, strains, and displacement in the implant system. This can affect the remodeling process of the bone around the implants [23]. In our study, the lowest minimum and maximum principal stress values in the bone tissue were found in model 3, that is, in the model with narrow diameter implants placed in place of the lateral teeth.

Tsumanuma et al. [3] examined the effect of cantilever in prostheses made with zirconia implants in the maxillary anterior region with FEM. The maximum principal stress value in the bone tissue was least seen in the implant model placed in the central region, then in the implant model placed in the central and lateral region, and in the implant models placed in the lateral region, respectively. It has been observed that as the distance between implants increases, the maximum stress value in the bone increases. In our study, maximum principal stress was lower in the model with standard implants in the lateral region than in the model with one lateral and one central region. This may be because we placed a standard diameter implant in the central region but a narrow diameter implant in the lateral region. Because when we look at the von mises values of the implants in these 3 groups, the highest was seen in the narrow diameter implant in the lateral region. Considering all groups in our study, it is thought that the higher maximum principal value in the bone in the model with narrow diameter implants placed in the lateral region is due to the large distance between implants, as in the study of Tsumanuma et al. [3] It is thought that the high von misses value of the implants in the same group is due to the narrow diameter of the implants.

In the treatment of missing 4 anterior teeth with 2 implants, both the central and lateral implants can be of standard diameter. In the study Corrêa et al. [23], both the implants placed in the central and lateral regions were of standard diameter. This is also an alternative. In some patients, resorption following the loss of the four maxillary incisors will be considerable. The reduced implant diameter and the implant distribution offer ideal base dimensions for implant crowns replacing the lateral incisors [5]. Since it was thought to be more appropriate for clinical use, a group was created in which a standard implant was placed in the central and a narrow diameter implant was placed in the lateral area.

Correa et al. [23] evaluated the stress analysis of the prostheses designed with 4 units of nickel-chromium alloy on 2 titanium implants and abutments in the anterior maxilla. Here, contrary to our case, the least stress was observed in the prosthesis on the implant placed on the lateral incisors. It is thought that these differences may be caused by the prosthetic materials. However, in a study by Silva et al. [4], they concluded that cantilever extensions can be used in fixed prostheses and do not adversely affect prosthesis survival and success or marginal bone loss.

The results of this study will help clinicians with the positioning of the implants and the planning of the prosthesis. It is considered appropriate to confirm the result with other studies.

Conclusion

According to the results obtained, the highest stress value in bone, implant, abutment, screw and prosthesis was seen in the treatment option with narrow diameter implants placed on the lateral incisors. But these values are below the limit considered to represent overload.

However, a D2 quality bone was designed in the study and 100% osseointegration was assumed. These values may be different in patients encountered in the clinic. For some reason, the teeth or dentures may be overloaded. In such cases, it is useful to avoid prostheses made by placing narrow-diameter implants on the laterals.

Conflict of Interests
The authors declare that there is no conflict of interest in the study.

Financial Disclosure
The authors declare that they have received no financial support for the study.

Ethical Approval
Ethics committee approval is not required.

References

1. Gialain IO, Rodrigues da Silva LF, Takano MKG, et al. Peri-implant bone resorption risk of anterior maxilla narrow single implants: a finite-element analysis. Biomater Investig Dent. 2022;9:92-100.
2. Homma H, Miyashima-Okada M, Nakauchi A, et al. Treatment of child with four lost maxillary incisors due to traffic injury. Bull Tokyo Dent Coll. 2019;60:211-20.
3. Tsumanuma KTS, Caldas RA, Silva ID, et al . Finite element analysis of stress in anterior prosthetic rehabilitation with zirconia implants with and without cantilever. Eur J Dent. 2021;15:669-74.
4. Freitas da Silva EV, Micheline dos Santos D, Sonego MV, et al. Does the presence of a cantilever influence the survival and success of partial implant-supported dental prostheses? Systematic review and meta-analysis. Int J Oral Maxillofac Impants. 2018;33:815-23.
5. Vailati F, Belser UC. Replacing four missing maxillary incisors with regular-or narrow-neck implants: analysis of treatment options. Eur J Esthet Dent. 2007;2:230-45.
6. Osman RB, Elkhadem AH, Ma S, Swain MV. Finite element analysis of a novel implant distribution to support maxillary overdentures. Int J Oral Maxillofac Impants. 2013;28:e1-10.
7. Bozyel D, Faruk ST. Biomechanical behavior of All-on-4 and M-4 configurations in an atrophic maxilla: a 3D finite element method. Med Sci Monit. 2021;27:e929908.
8. Saab XE, Griggs JA, Powers JM, Elgelmeier RL. Effect of abutment angulation on the strain on the bone around an implant in the anterior maxilla: a finite element study. J Prosthet Dent. 2007;97:85-92.
9. Verri FR, Santiago Jr JF, Almeida DAF, et al. Biomechanical three-dimensional finite element analysis of single implant-supported prostheses in the anterior maxilla, with different surgical techniques and implant types. Int J Oral Maxillofac Implants. 2017;32:e191-8.
10. Kim MJ, Hong SO. Finite element analysis on stress distribution of maxillary implant-retained overdentures depending on the Bar attachment design and palatal coverage. J Adv Prosthodont. 2016;8:85-93.
11. Yang GY, Chen L, Gao Y, et al. Risk factors and reoperative survival rate of failed narrow-diameter implants in the maxillary anterior region. Clin Implant Dent Relat Res. 2020;22:29-41.
12. Okumura N, Stegaroiu R, Kitamura E, et al. Influence of maxillary cortical bone thickness, implant design and implant diameter on stress around implants: a three-dimensional finite element analysis. Journal of Prosthodontic Research. 2010;54:133-42.
13. Gümrükçü Z, Korkmaz YT. Influence of implant number, length, and tilting degree on stress distribution in atrophic maxilla: a finite element study. Med Biol Eng Comput. 2018;56:979-89.

14. Lin CL, Chang SH, Chang WJ, Kuo YC. Factorial analysis of variables influencing mechanical characteristics of a single tooth implant placed in the maxilla using finite element analysis and the statistics-based Taguchi method. Eur J Oral Sci. 2007;115:408-16.

15. Lee JS, Lim YJ. Three-dimensional numerical simulation of stress induced by different lengths of osseointegrated implants in the anterior maxilla. Comput Methods Biomech Biomed Engin. 2013;16:1143-9.

16. Alikhasi M, Siadat H, Geramy A, Ahangari AH. Stress distribution around maxillary anterior implants as a factor of labial bone thickness and occlusal load angles: a 3-dimensional finite element analysis. Journal of Oral Implantology. 2014;40:37-42.

17. Momberger N, Mukaddam K, Zitzmann NU, et al. Esthetic and functional outcomes of narrow-diameter implants compared in a cohort study to standard diameter implants in the anterior zone of the maxilla. Quintessence Int. 2022;53:502-9.

18. Sahin SC. Static and dynamic stress analysis of standard-and narrow-diameter implants: a 3D finite element analysis. Int J Oral Maxillofac Implants. 2020;35:e58-68.

19. Galbusera F, Taschieri S, Tsesis I, et al. Finite element simulation of implant placement following extraction of a single tooth. J Appl Biomater Funct Mater. 2014;12:84-9.

20. Wu D, Tian K, Chen J, et al. A further finite element stress analysis of angled abutments for an implant placed in the anterior maxilla. Comput Math Methods Med. 2015;2015:560645.

21. Talmazov G, Veilleux N, Abdulmajeed A, Bencharit S. Finite element analysis of a one-piece zirconia implant in anterior single tooth implant applications. PLoS ONE. 2020;15:e0229360.

22. Kapoor S, Rodrigues S, Mahesh M, et al. Evaluation of stress generated with different abutment materials and angulations under axial and oblique loading in the anterior maxilla: three-dimensional finite element analysis. Int J Dent. 2021;2021:9205930.

23. Corrêa CB, Margonar R, Noritomi PY, Vaz LG. Mechanical behavior of dental implants in different positions in the rehabilitation of the anterior maxilla. J Prosthet Dent. 2013;111:301-9.

24. Wakimoto M, Matsumura T, Ueno T, et al. Bone quality and quantity of the anterior maxillary trabecular bone in dental implant sites. Clin Oral Impl Res. 2012;23:1314-9.

25. Osman MLM, Lim TW, Chang HC, et al. Structural integrity of anterior ceramic resin-bonded fixed partial denture: a finite element analysis study. J Funct Biomater. 2023;14:108.