JO JOURNAL OF OSSEOINTEGRATION periodontics and prosthodontics

Assessment of the efficacy of posterior extra-short implant support for an interforaminal implant-supported fixed full-arch mandibular prosthesis

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TO CITE THIS ARTICLE
Can Tükel H, Küçükkurt S. Assessment of the efficacy of posterior extra-short implant support for an interforaminal implant-supported fixed full-arch mandibular prosthesis. J Osseointegr 2020;12(2):181-188.

DOI 10.23805 /JO.2020.12.02.19

ABSTRACT

Aim The purpose of the present study was to determine whether it is useful to support a fixed full-arch prosthesis supported by interforaminal implants, with extra-short implants (4 mm) in the posterior region in order to eliminate the cantilever extensions, in posterior atrophic mandible cases.
Methods Six different models including three or four interforaminal implants with or without support of posterior extra-short implants were formed. Straumann tissue-level implants (4.1x12mm and 4.1x4mm) were modeled for this study. Spherical loadings from canine and molar regions were applied to evaluate tension, compression, and von Mises stresses by implementing finite element analysis.
Results In most conditions, four interforaminal implant supports provide balanced stress distributions, on the other hand, only three interforaminal implants were found to be insufficient biomechanically. The support of interforaminal implants with extra-short implants in the posterior region did not show the expected contribution, especially against the forces in the canine region. Also, the placement of four posterior extra-short implants does not make significant difference compared to the placement of two extra-short implants.
Conclusions Implant-supported fixed prosthetic rehabilitation with cantilever extension of an edentulous mandible supported by four implants in the interforaminal region reached the best biomechanical results of the present study.

KEYWORDS Dental implants; Finite Element Analysis; Full mouth rehabilitation; Interforaminal, extra-short implants.

INTRODUCTION

The implant-supported rehabilitation of the atrophic posterior mandible is always challenging for the clinicians. Various surgical procedures, including guided bone regeneration, block grafting, and nerve transposition, have been proposed to compensate for bone volume. However, these surgical procedures have several disadvantages (1-3). On the other hand, less invasive options have been developed, including short implants and implant placement in the interforaminal region. Both methods aim to avoid more complex, invasive, and time-consuming procedures. One treatment option is to use the bone in the interforaminal region, which is less affected by resorption (4-8). Traditionally, up to six implants in the interforaminal region have been used to support a total fixed prosthesis with posterior cantilevers (7). Several researchers challenged this concept by gradually reducing the number of implants placed in the interforaminal region (9, 10).
The improvements in material durability and dental implant designs have enabled the use of shorter implants when there is a limited bone height in the posterior mandible. In the literature, implants of 7 to 9 mm were defined as short (11, 12) and implants shorter than 7 mm were defined as extra short (13-16). Nowadays, it is a predictable option to restore an atrophic posterior mandible with 4 mm extra short implants (14, 17, 18).
This study aimed to compare the stress distribution around the bone and implants caused by fixed full-arch mandibular prosthesis supported by interforaminal implants with or without posterior extra short implants using finite element analysis. This study hypothesizes that eliminating cantilever extension with extra short implants results in more balanced stress distribution. Besides, to the best of our knowledge, in the literature, a limited number of studies exist on 4 mm extra short implants, and these implants were not simulated before using a finite element analysis.

MATERIALS AND METHODS

Implant and prosthesis material properties

Straumann standart plus tissue level (Roxolid®, Institute Straumann AG, Basel, Switzerland) implants with a 1.8 mm machined surface neck were modeled for the study. Regular implants (4.1x12mm) and extra short implants (4.1x4mm) were used in the interforaminal region and the posterior region, respectively. The implants were made of titanium-zirconium (Ti-Zr) alloy (Roxolid®).

The prosthesis was designed as a titanium framework with cantilevers and a superstructure with a wrap-around acrylic denture base and 12 feldspathic porcelain teeth. Implants and prosthesis are connected through screws via multiunit abutments of the respective company.

Models

Six different models including three or four interforaminal implants, with or without support of posterior extra short implants were formed and were labeled according to the configuration and numbers of implants (A, Anterior; P, Posterior) (Fig. 1).

- Model 3A: Three interforaminal implants.
- Model 4A: Four interforaminal implants.
- Model 3A2P: Three interforaminal implants and two extra short implants.
- Model 3A4P: Three interforaminal implants and four extra short implants.
- Model 4A2P: Four interforaminal implants and two extra short implants.
- Model 4A4P: Four interforaminal implants and four extra short implants.

In the 4-implant models, the anterior implants were placed in the lateral tooth region, and the posterior implants were placed in the 1st premolar region in the interforaminal region. In 3-implant models, two of the interforaminal implants were positioned in the 1st premolar region and one in the midline. Extra short implants were placed in the 1st molar region in 2 extra

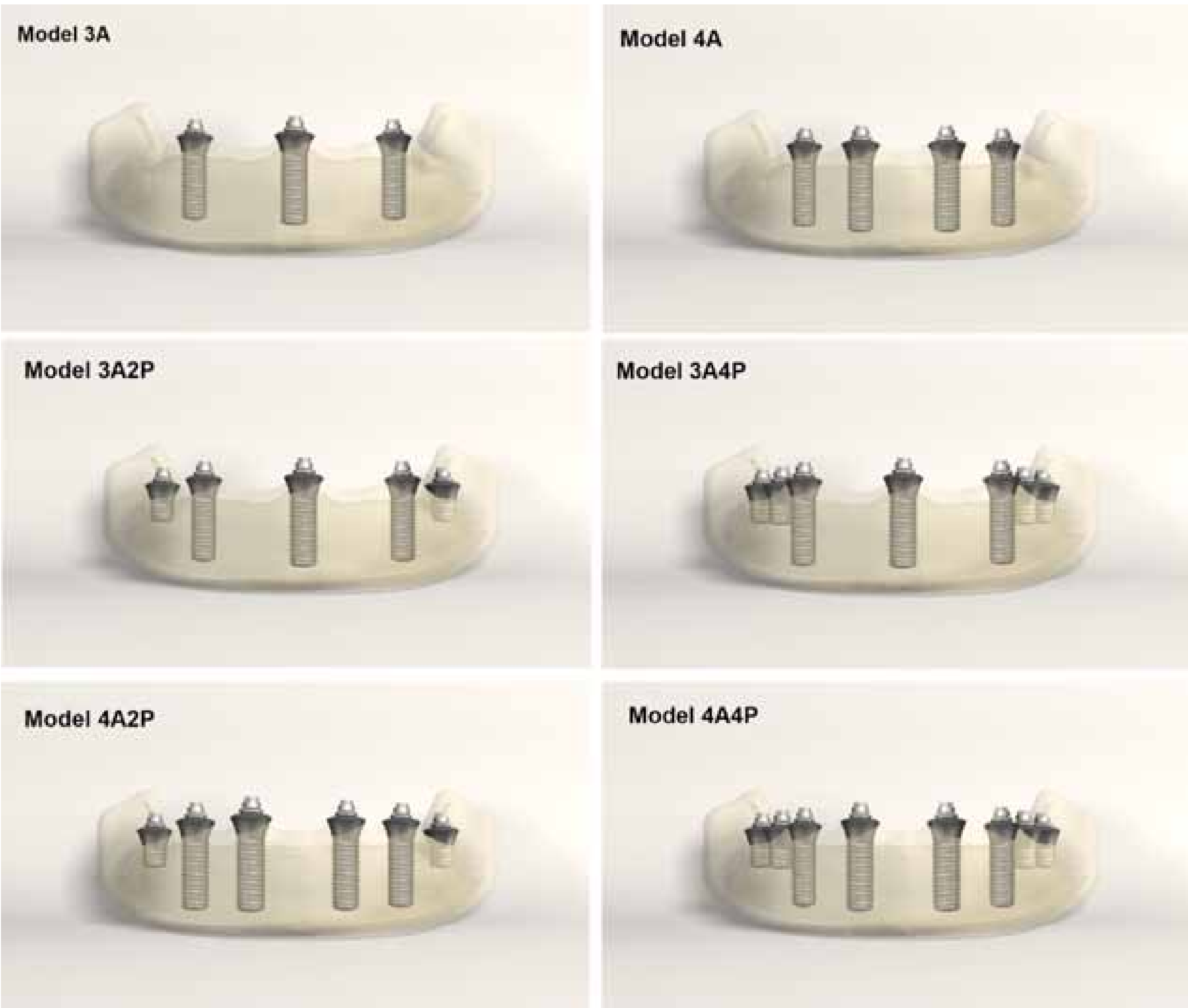

FIG. 1 The models of the present study.

	Young's Modulus (MPa)	Poisson ratio
Cortical Bone	13700	0.3
Trabecular Bone	1370	0.3
Ti-Zr implant (Roxolid)	100000	0.3
Titanium	117000	0.35
Acrylic material	3000	0.35
Feldspathic porcelain	82 800	0.35

TABLE 1 Mechanical properties of the materials.

short implant-supported models, and the 2nd premolar and 1st molar in 4 extra short implant-supported models.

Modeling

The present study was performed after obtaining computed tomography images of a patient with vertical atrophy in the posterior region and adequate bone volume and height in the anterior region, which were converted in a Digital Imaging and Communications in Medicine (DICOM) format. Then, this data modified with the use of the VRMESH (VirtualGrid) and Rhinoceros 4.0 (McNeel North America) software. Edentulous mandible for the models reconstructed as trabecular bone covered with a 2-mm cortical bone, bone width of 8 mm along the entire alveolar crest, bone height of 6 mm between the mandibular canal and alveolar crest in the posterior, and 14 mm in the interforaminal region were defined. The distances of right and left mental foramina from midline were arranged as 25 mm with a total 50 mm interforaminal distance. The distances of mental foramen from the lower and upper borders of the mandible were arranged as 8 and 5 mm, respectively. The diameter of the mental foramen was modeled as 3.5 mm. Also, the mandible covered was with a 2-mm thick mucosa.
The implants and prosthetic superstructures were scanned using a three-dimensional (3D) scanner (Activity 880, Smart Optics Sensortechnik) within a 10 -µm accuracy ratio, and imported to VRMESH software. All structures were modeled using Rhinoceros 4.0.

Boundary and loading conditions

Boundary conditions of the study were modeled as fixed in all directions. Modeled structures were simulated as tightly bonded. It was assumed that load transfers are performed according to the internal characteristics of the cortical and trabecular bones. The connection between the implants and the supporting tissues is designed to directly transfer the loads between the multiunit abutments and implants and the multiunit abutments and the prosthetic material. Moreover, it was assumed that the implants are 100% osseointegrated. All materials used in this study are defined as homogeneous, isotropic, and linear elastic. The material characteristics of the prosthetic material, mucosa, cortical bone, trabecular bone, and implants were determined according to a similar study (19) (Table 1).
The finite element models were exported to ALGOR FEMPRO software (Algor) for 3D static analysis. To simulate the chewing forces more naturally, an occlusal load of 100 N was applied from a spherical solid material (12 mm in diameter), which places the foodstuff to both anterior (canine) and posterior (first molar) regions (Fig. 2).

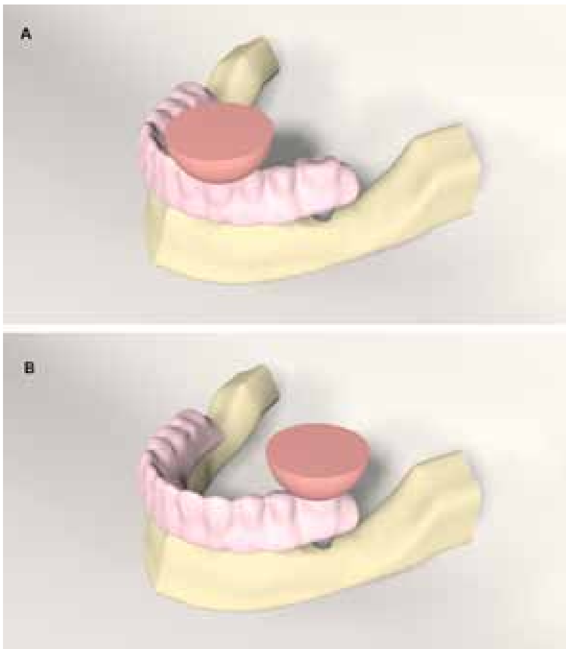

FIG. 2 Spherical loading applied from the canine region (A). Spherical loading applied from the molar region (B).

Analysis

Principal stresses were evaluated for fragile structures such as bone. Maximum principal stress (Pmax) represents tension stress type, and minimum principal stress (Pmin) represents compression type stresses. Von Mises stresses were analyzed for evaluating stress formation in implants. All stresses were measured in megapascals (MPa). Because the data obtained from finite element analysis were mathematical calculations without variance, the results were not analyzed statistically and instead evaluated with scales. All stress values are shown using color and quantity scales.

RESULTS

Maximum principal stress (Pmax)

Against the forces applied from the canine region, the highest Pmax on the cortical bone was observed in the 3A2P model with 15.4 MPa. Minimally decreased Pmax

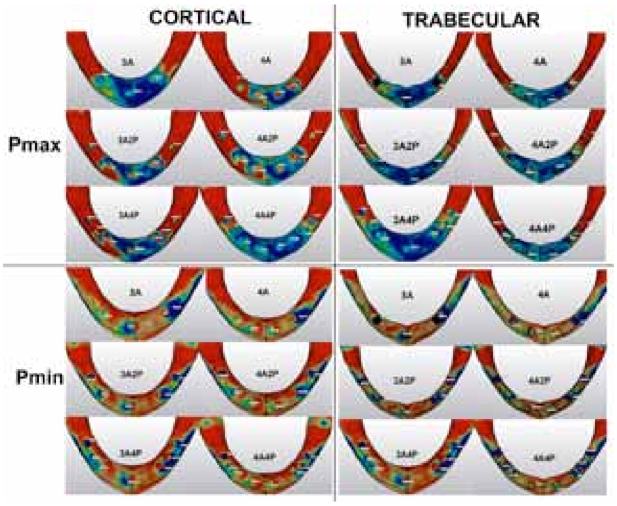

FIG. 3 Compression and tension stresses in cortical and trabecular bone against forces from the canine region.

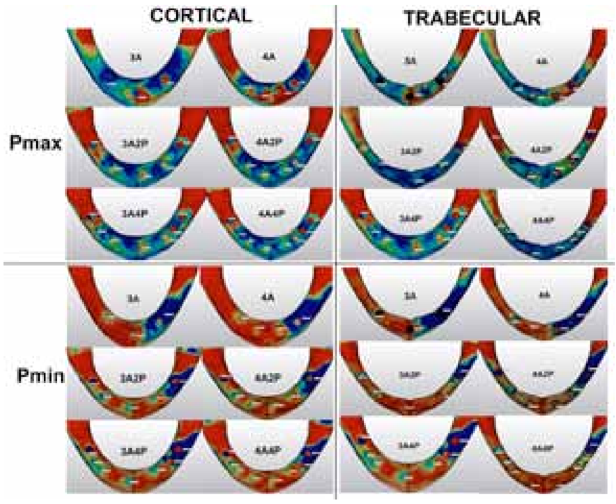

FIG. 4 Compression and tension stresses in cortical and trabecular bone against forces from the molar region.

levels were observed in 3A4P (14.1 MPa), 4A2P (14.4 MPa), and 4A4P (13.5 MPa) models. The lowest Pmax was observed in the 3A model with 3.3 MPa. In the trabecular bone, the highest and lowest Pmax values occurred in the 4A2P model (4.7 MPa) and 4A model with 0.7 MPa, respectively. It is noteworthy that in the trabecular bone, the lowest Pmax was observed in models without posterior implant support (Fig. 3, 5).
Against the forces applied from the molar region on the cortical bone, the highest Pmax was observed in the 3A model (6.9 MPa), and the lowest Pmax was observed in the 4A model with 3.7 MPa. In the trabecular bone, the highest Pmax occurred in the 3A model with 5.5 MPa, and the lowest occurred in the 3A4P model with 0.4 MPa (Fig. 4, 6).

Minimum principal stresses (Pmin)

When the stresses on the cortical bone against the forces applied from the canine region were evaluated, the highest Pmin was observed in the 3A4P model with –11,4 MPa, and the lowest Pmin was observed in the 3A2P model with –6.6 MPa. The other model with 4 posterior implants (4A4P) also created high Pmin (-10 MPa), while the other models produced relatively low stresses close to each other. In the trabecular bone, the highest Pmin was observed in the 3A2P model with –3.2 MPa, and the lowest was observed in the 4A model with –0.6 MPa. While the stress values were generally low, the models without posterior implant support (3A: -1.1 MPa and 4A: - 0,6 MPa) had lower Pain values (Fig. 3, 5).
When the stresses in the cortical bone were observed against the forces applied in the molar region, the highest Pmin was observed in the 3A group with –22.1 MPa, and the lowest was observed in the 4A2P model with –11.2 MPa. Also, 3A2P (-11,3 MPa) and 4A4P (-11,4 MPa) models produced relatively low stresses close to 4A2P. In the trabecular bone, the highest Pmin stress was –3.2 MPa in the 3A model, whereas the lowest Pmin stress occurred in the 4A2P model with -0.5 MPa (Fig. 4, 6).

Stresses on implants (von Mises)

When the stresses on the implants were evaluated as a result of the forces applied in the canine region, the lowest stress was observed in the 4A2P model with 18 MPa, and the highest stress was observed in the 3A model with 47.4 MPa. Stress values in the implants as a result of the forces applied from the canine region are similar except the 3A model (Fig. 7).
Against the forces applied from the molar region, models not supported with extra short implants were subjected to extremely high stresses compared with models supported with posterior extra short implants. Although stress values in the 3A and 4A models were 51.8 MPa and 49.8 MPa, respectively, stresses in the other models were less than half of these stresses and under 20 MPa. Even in the 3A4P and 4A2P models, stresses are less than 10 MPa. Unexpectedly in the 4A4P model, higher stresses (18.9 MPa) were observed than in the 4A2P model (9.8 MPa) (Fig. 7).

DISCUSSION

The hypothesis of this study could not be fully confirmed. According to the results of this study, prosthetic rehabilitation with cantilever extension supported by only four implants placed in the interforaminal region can be used safely in most cases, biomechanically. However, considering the high stresses on the implants against forces from the molar region, supporting interforaminal implants with two extra short implants in the posterior could be a more risk-free approach, in cases where excessive forces may be imposed on prostheses.

High-stress values were observed in most of the scenarios for the 3A model; however, these values returned to the study average with an additional interforaminal implant (4A model). When posterior extra short implant-supported models are compared, four extra short implants support, in general, causes less stress formation and distributes the stresses on the bones and implants in the posterior region in a more balanced manner than two- extra short implant support. Even so, in several scenarios, the stress formations between four extra short implant support and two extra short implant support was minimal. Therefore, it is often unnecessary to increase the number of extra short implants in the posterior region, considering that it will increase costs and be more invasive. Similarly, no significant difference was observed between the extra short implant-supported models supported by three or four implants in the interforaminal region in many conditions. Therefore, the placement of three or four implants in the interforaminal region does not cause significant differences as long as extra short implant support is provided in the posterior region.

Although the augmentation of the posterior atrophic mandible with various procedures or repositioning of the mandibular nerve that restricts the vertical height has been found successful in various studies, it has negative aspects in terms of both increased costs and requiring interventional procedures involving various risks and extending treatment time (1-3, 15, 20). Nowadays, patient expectations and treatment choices of clinicians are solving the problem in the shortest period and with conservative treatment methods. It has been suggested that short implants may be a suitable alternative for longer implants in cases requiring additional augmentation procedures (1, 2, 11-13, 15, 21, 22).

Owing to the developments in the macro and micro designs, the implants have been developed using narrower diameters and lesser lengths, and their strengths in these dimensions have improved over time. As a result of these developments, the acceptable length of short implants has decreased from 10 mm (11, 12) to 6 mm (2, 13), and to 4 mm (17, 18) for extra short implants. Although the acceptable length of the short implants has changed over time, the reported success rates remain similar (23-25). In our study, the lowest possible bone volume that allows the implant placement in the posterior mandibular region was estimated, and implants of 4.1 mm diameter and 4 mm length, which were the shortest implants in the current market, were used. The data on 4 mm implants are not adequate to make any firm conclusion. One of the few studies conducted by Slotte et al. (18) reported that 4 mm implants allow fixed prosthetic rehabilitation in the

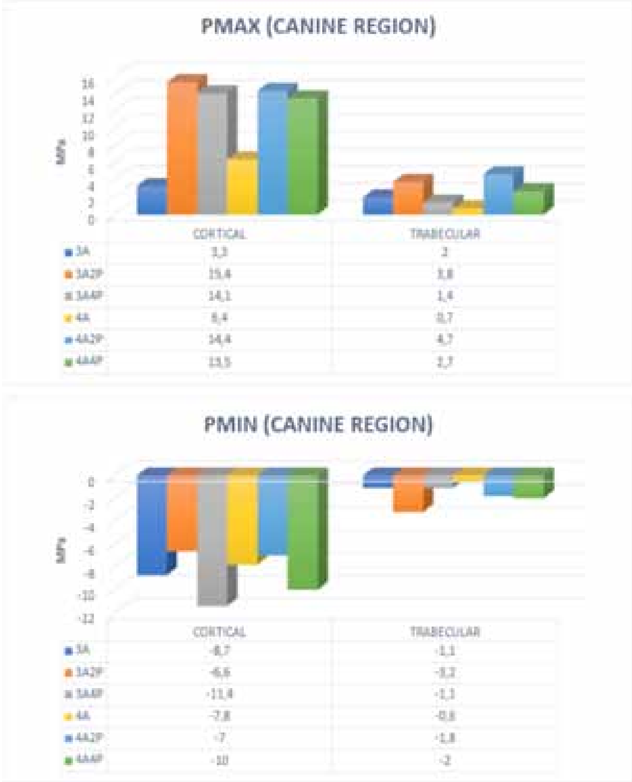

FIG. 5 Pmax and Pmin stresses occurring on the bone surrounding the implant against the forces applied against forces from canine region.

FIG. 6 Pmax and Pmin stresses occurring on the bone surrounding the implant against the forces applied against forces from molar region.

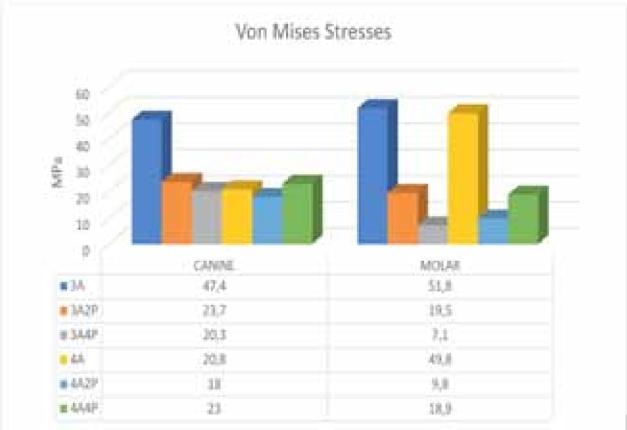

FIG. 7 Von Mises stresses on the implants in models against the forces applied.

mandible in healthy peri-implant conditions as observed in a 2-year follow-up of 87 extra short implants placed on the atrophic posterior mandible. In the 5-year follow-up of the same study, 86 extra short implants had a survival rate of 92.2% (17). Our results showed that extra short implants placed in the posterior region provide a more balanced stress distribution, especially against the stresses occurring on the implants. When the stresses in the bones were evaluated, the results did not create a significant difference compared to the 4A model. In the extra short implant studies performed by Slotte et al. (17, 18), implant placement was performed with one implant per missing tooth in the posterior region. In the results of this study, although there were stress differences between one and two extra short implant placements in favor of two extra short implant placement, however, this difference was not significantl.
With the increasing usage rates of dental implants, the planning of rehabilitation of the completely edentulous mandible with implant-supported fixed prostheses has changed over time. From the studies using 6 or more implants for rehabilitation of a full edentulous mandible, there have been changes ranging from the studies that claim that the rehabilitation of the mandible with 3 or even only 2 implants yields successful results (26, 27). Moraschini et al. (4) reported that full-arch fixed prostheses in the mandible supported by two and four implants exhibit a low rate of failure, low marginal bone loss, and low biomechanical and biological complication rates for implants and prostheses. Krennmair et al. (5) reported a success rate of 98.6% in 38 patients who received support from four implants placed in the interforaminal region of the mandible. In the present study, six different scenarios, including three to four implants in the interforaminal region, and two to four extra short implants supporting these implants in the posterior region, were compared. According to the results of the present study, suitable stress distributions were observed in 4 interforaminal implants (4A model); however, 3 interforaminal implants (3A) were exposed to high stresses up to 2 times in some scenarios.
The use of three implants to rehabilitate the edentulous mandible was first described by P.I. Brånemark et al. (10), Novum protocol, and the researchers reported a success rate of 98% in three years and 93.3% in five years (9). Inspired by this technique, Hatano et al. (28) used a similar treatment option in the following years using standard implants. Also, they reported that in a five-year follow-up of the three standard design implants placed in the interforaminal area in the edentulous mandible, it would be sufficient to support fixed prosthetic rehabilitation even in the immediate loading condition (8). However, the stress values obtained from the results of the present study indicate that full-arch fixed prosthesis supported by only 3 implants was not considered appropriate due to the high stresses that occurred on the models.
There are studies suggesting that three implants are insufficient for the rehabilitation of a full edentulous mandible. Heydecke et al. (29) reported that the use of four to six implants for implant-supported fixed full-arch prostheses in their systemic review was a well-documented treatment option in studies with an estimated 5-year survival rate. The researchers emphasized that the use of three implants will not have similar survival rates. In their photoelastic studies, Simamoto Jr et al. (30) claimed that a reduction in the number of implants placed in the interforaminal region in the posterior atrophic mandible might result in a higher stress concentration around the implants; therefore, the use of five implants instead of three implants may lead to a lower stress concentration and a lower biomechanical complication rate. Fazi et al. (31), in their biomechanical study, reported that the three parallel implant configurations resulted in higher stress than the four implants in the implant and bone. Correa et al. (32) compared the rehabilitation of the edentulous mandible with three and four implant-supported cantilever extension prostheses placed in the interforaminal area and did not recommend the three implant-supported prostheses because of inadequately supported occlusal loads. In the present study, significantly different stress values were observed between the models containing 3 implants and 4 implants. These results are consistent with the studies showing that 3 implants are not sufficient, suggesting the placement of at least 4 implants.
Although it is known that full-arch prostheses with implant-supported cantilever extension provide successful results in general, and it is a safe treatment option, studies have shown that cantilever extensions cause some technical complications (6, 33-38). Supporting these cantilever extensions with extra short implants in the posterior atrophic mandible may prevent these complications. In their biomechanical study, Ogawa et al. (39) reported that supporting cantilever extension with short implants in the posterior

region produced better stress values regarding axial and bending forces than non-supported prostheses and argued that the cantilever extensions should be supported with short dental implants in the posterior region. The results of the present study, in accordance with those reported by Ogawa et al. (39), indicate that placing extra short implants in the posterior region to support cantilevers, the stresses on the implants can be better balanced by distributing unstable forces.

CONCLUSIONS

Prosthetic rehabilitation with cantilever extension supported by four implants placed in the interforaminal region can be used safely in most cases biomechanically; however, considering the high von Mises stresses occurred on the implants against forces from the molar region, supporting these systems with at least two extra short implants in the posterior region could be a more risk-free approach. Besides, only three interforaminal implants without extra short implant support were found to be insufficient in almost all conditions. Among the models supported by extra short implants, the models with four implants in the interforaminal region caused less stresses compared with those with three implants; similarly, the placement of four extra short implants in the posterior areas reduces the stress on the implants and bone compared with that of two extra short implants. However, in both cases, the differences are not extremely significant. Therefore, in most cases, the support of two extra short implants could be sufficient.

REFERENCES

1. de NDFJ, Pecorari VGA, Martins CB, Del Fabbro M, Casati MZ. Short implants versus bone augmentation in combination with standard-length implants in posterior atrophic partially edentulous mandibles: systematic review and meta-analysis with the Bayesian approach. Int J Oral Maxillofac Surg 2018.
2. Pieri F, Forlivesi C, Caselli E, Corinaldesi G. Short implants (6mm) vs. vertical bone augmentation and standard-length implants (>/=9mm) in atrophic posterior mandibles: a 5-year retrospective study. Int J Oral Maxillofac Surg 2017;46:1607-1614.
3. Abayev B, Juodzbalys G. Inferior alveolar nerve lateralization and transposition for dental implant placement. Part I: a systematic review of surgical techniques. J Oral Maxillofac Res.2015;6:e2.
4. Moraschini V, Velloso G, Luz D, Cavalcante DM, Barboza Edos S. Fixed Rehabilitation of edentulous mandibles using 2 to 4 implants: a systematic review. Implant Dent 2016;25:435-444.
5. Krennmair G, Seemann R, Weinlander M, Krennmair S, Piehslinger E. Clinical outcome and peri-implant findings of four-implant-supported distal cantilevered fixed mandibular prostheses: five-year results. Int J Oral Maxillofac Implants 2013;28:831-840.
6. Malo P, de Araujo Nobre M, Lopes A. The prognosis of partial implant-supported fixed dental prostheses with cantilevers. A 5-year retrospective cohort study. Eur J Oral Implantol 2013;6:51-59.
7. Turkyilmaz I, Jones JD. Long term success of 6 implants supporting a mandibular screw-retained fixed dental prosthesis: a clinical report. J Prosthet Dent 2012;107:280-283.
8. Hatano N, Yamaguchi M, Yaita T, Ishibashi T, Sennerby L. New approach for immediate prosthetic rehabilitation of the edentulous mandible with three implants: a retrospective study. Clin Oral Implants Res 2011;22:1265-1269.
9. Engstrand P, Grondahl K, Ohrnell LO, Nilsson P, Nannmark U, Branemark PI. Prospective follow-up study of 95 patients with edentulous mandibles treated according to the Branemark Novum concept. Clin Implant Dent Relat Res 2003;5:3-10.
10. Branemark PI, Engstrand P, Ohrnell LO, Grondahl K, Nilsson P, Hagberg K, et al. Branemark Novum: a new treatment concept for rehabilitation of the edentulous mandible. Preliminary results from a prospective clinical follow-up study. Clin Implant Dent Relat Res 1999;1:2-16.
11. Monje A, Fu JH, Chan HL, Suarez F, Galindo-Moreno P, Catena A, et al. Do implant length and width matter for short dental implants (<10 mm)? A meta-analysis of prospective studies. J Periodontol 2013;84:1783-1791.
12. Schwartz SR. Short implants: are they a viable option in implant dentistry? Dent Clin North Am 2015;59:317-328.
13. Pommer B, Mailath-Pokorny G, Haas R, Buseniechner D, Millesi W, Furhauser R. Extra-short (< 7 mm) and extra-narrow diameter (< 3.5 mm) implants: a meta-analytic literature review. Eur J Oral Implantol 2018;11 Suppl 1:S137-S146.
14. Calvo-Guirado JL, Morales-Melendez H, Perez-Albacete Martinez C, Morales-Schwarz D, Kolerman R, Fernandez-Dominguez M, et al. Evaluation of the Surrounding Ring of Two Different Extra-Short Implant Designs in Crestal Bone Maintanence: A Histologic Study in Dogs. Materials (Basel) 2018;11.
15. Shah SN, Chung J, Kim DM, Machtei EE. Can extra-short dental implants serve as alternatives to bone augmentation? A preliminary longitudinal randomized controlled clinical trial. Quintessence Int 2018;49:635-643.
16. Bordin D, Bergamo ETP, Bonfante EA, Fardin VP, Coelho PG. Influence of platform diameter in the reliability and failure mode of extra-short dental implants. J Mech Behav Biomed Mater 2018;77:470-474.
17. Slotte C, Gronningsaeter A, Halmoy AM, Ohrnell LO, Mordenfeld A, Isaksson S, et al. Four-Millimeter-Long Posterior-Mandible Implants: 5-Year Outcomes of a Prospective Multicenter Study. Clin Implant Dent Relat Res 2015;17 Suppl 2:e385-395.
18. Slotte C, Gronningsaeter A, Halmoy AM, Ohrnell LO, Stroh G, Isaksson S, et al. Four-millimeter implants supporting fixed partial dental prostheses in the severely resorbed posterior mandible: two-year results. Clin Implant Dent Relat Res 2012;14 Suppl 1:e46-58.
19. Ozan O, Kurtulmus-Yilmaz S. Biomechanical Comparison of Different Implant Inclinations and Cantilever Lengths in All-on-4 Treatment Concept by Three-Dimensional Finite Element Analysis. Int J Oral Maxillofac Implants 2018;33:64-71.
20. Anitua E, Alkhraisat MH, Orive G. Novel technique for the treatment of the severely atrophied posterior mandible. Int J Oral Maxillofac Implants 2013;28:1338-1346.
21. Pimentel MJ, Silva WJ, Del Bel Cury AA. Short implants to support mandibular complete dentures - photoelastic analysis. Braz Oral Res 2017;31:e18.
22. Atieh MA, Zadeh H, Stanford CM, Cooper LF. Survival of short dental implants for treatment of posterior partial edentulism: a systematic review. Int J Oral Maxillofac Implants 2012;27:1323-1331.
23. Han J, Zhang X, Tang Z, Zhang L, Shi D, Meng H. A prospective, multicenter study assessing the DENTSPLY Implants, OsseoSpeed() TX, length 6 mm in the posterior maxilla and mandible: a 1-year follow-up study. Clin Oral Implants Res 2016;27:452-457.
24. Tabrizi R, Arabion H, Aliabadi E, Hasanzadeh F. Does increasing the number of short implants reduce marginal bone loss in the posterior mandible? A prospective study. Br J Oral Maxillofac Surg 2016;54:731-735.
25. Seemann R, Marincola M, Seay D, Perisanidis C, Barger N, Ewers R. Preliminary results of fixed, fiber-reinforced resin bridges on four 4- x 5-mm ultrashort implants in compromised bony sites: a pilot study. J Oral Maxillofac Surg.2015;73:630-640.
26. Cannizzaro G, Felice P, Soardi E, Ferri V, Leone M, Lazzarini M, et al. Immediate loading of 2(all-on-2) versus 4 (all-on-4) implants placed with

a flapless technique supporting mandibular cross-arch fixed prostheses: 1-year results from a pilot randomised controlled trial. Eur J Oral Implantol 2013;6:121-131.

27. Oliva J, Oliva X, Oliva JD. All-on-three delayed implant loading concept for the completely edentulous maxilla and mandible: a retrospective 5-year follow-up study. Int J Oral Maxillofac Implants 2012;27:1584-1592.
28. Hatano N, Yamaguchi M, Suwa T, Watanabe K. A modified method of immediate loading using Branemark implants in edentulous mandibles. Odontology 2003;91:37-42.
29. Heydecke G, Zwahlen M, Nicol A, Nisand D, Payer M, Renouard F, et al. What is the optimal number of implants for fixed reconstructions: a systematic review. Clin Oral Implants Res 2012;23 Suppl 6:217-228.
30. Simamoto Junior PC, da Silva-Neto JP, Novais VR, de Arruda Nobilo MA, das Neves FD, Araujo CA. Photoelastic stress analysis of mandibular fixed prostheses supported by 3 dental implants. Implant Dent 2014;23:704-709.
31. Fazi G, Tellini S, Vangi D, Branchi R. Three-dimensional finite element analysis of different implant configurations for a mandibular fixed prosthesis. Int J Oral Maxillofac Implants 2011;26:752-759.
32. Correa S, Ivancik J, Isaza JF, Naranjo M. Evaluation of the structural behavior of three and four implant-supported fixed prosthetic restorations by finite element analysis. J Prosthodont Res 2012;56:110-119.
33. Gallucci GO, Doughtie CB, Hwang JW, Fiorellini JP, Weber HP. Five-year results of fixed implant-supported rehabilitations with distal cantilevers for the edentulous mandible. Clin Oral Implants Res 2009;20:601-607.
34. Torrecillas-Martinez L, Monje A, Lin GH, Suarez F, Ortega-Oller I, Galindo-Moreno P, et al. Effect of cantilevers for implant-supported prostheses on marginal bone loss and prosthetic complications: systematic review and meta-analysis. Int J Oral Maxillofac Implants 2014;29:1315-1321.
35. Stafford GL. Survival rates of short-span implant-supported cantilever fixed dental prostheses. Evid Based Dent. 2010;11:50-51.
36. Balevi B. Implant-supported cantilevered fixed partial dentures. Evid Based Dent 2010;11:48-49.
37. Zurdo J, Romao C, Wennstrom JL. Survival and complication rates of implant-supported fixed partial dentures with cantilevers: a systematic review. Clin Oral Implants Res 2009;20 Suppl 4:59-66.
38. Anderson JD. Ten-year survival rate for cantilevered fixed partial dentures. Evid Based Dent.2005;6:96-97.
39. Ogawa T, Dhaliwal S, Naert I, Mine A, Kronstrom M, Sasaki K, et al. Effect of tilted and short distal implants on axial forces and bending moments in implants supporting fixed dental prostheses: an in vitro study. Int J Prosthodont 2010;23:566-573.