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The Effects of Bar Holder Material, Cantilever and Vertical Misfit on Stresses in Implant Supported Overdentures: Three Dimensional Finite Element Analysis

SUMMARY

Background/Aim: *The aim of this study is to examine with finite element analysis the distal bar extension, the bar substructure material type and the amount of bar substructure-abutment mismatch, and the stress caused by the implant at the surrounding bone tissue in bar-retained prostheses.* ***Material and Methods:*** *A bar-retained prosthesis model has been designed on three implants placed in the fully toothless lower jaw at the places of both canines and the midline. Bar holder according to distal cantilever lengths was modeled to be 0 mm, 8 mm and 14 mm. The vertical incompatibility of the bar holder substructure with the abutment was modeled to be 0 μm, 100 μm and 200 μm. A total of twenty-seven (3x3x3) different models were obtained with three different bar infrastructure materials (titanium, gold and chromium-cobalt). 150 N occlusal force was applied to the central fossa of the left 1st molar tooth with a rigid food stuff.* ***Results:*** *In the cortical bone, the highest maximum principle stress value (2.78 MPa) was analyzed around the anterior implant socket in the model 13 (gold, cantilever 0mm, misfit 100 μm). The highest von Mises stress value (343.43 MPa, which occurred at the selected joints in bar holders) was observed in model 27 (chrome-cobalt, cantilever 14mm, misfit 200 μm).* ***Conclusions:*** *When the length of the cantilever is 14 mm, it causes a significant increase in stress around the implant, especially near the cantilever. It has been observed that bar infrastructures with high elastic modulus create higher stress values.*

Keywords: Dental Implant, Finite Element Analysis, Overdenture

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Introduction

Implant-supported restorations are the type of treatment applied in cases of partial or complete edentulism. Implant supported prostheses may be fixed and removable. Purpose of implant treatment is to provide predictable and economical treatment options that can meet the patient's expectations and needs[1]. The literature and clinical experience show that the implant-supported prosthesis provides better stability, function and higher satisfaction results when compared to traditional full dentures[2,3,4].

Connection between implant and prosthesis is provided by attachment systems with different infrastructure, shape, retention capacity and flexibility. These are ball-attachment, bar attachment, telescopic attachment, magnet attachment, locator attachment, era attachment systems. Concerning the amount of retention, it has been reported that systems with the most bar holder and least magnet holder are used[5,6].

The use of bar attachment in implant supported overdentures started in 1980 [7]. Bar holders are elements that provide retention and stability by connecting two or more supports together, and by connecting the supports together, they share the functional forces between the implants, thus helping to protect the supports. They provide good retention and stabilization[8,9].

Adaptation disorders that may occur in implant superstructures, on the other hand, cause tensile, compression and sprain type forces at the bone implant interface due to the lack of flexibility. In cases where passive fit is not correct, many problems such as screw loosening, breakage, implant fractures, superstructure fractures, bone loss around the implant and loss of osseointegration may occur[10,11].

In the treatment of edentulous jaws, over-implant infrastructures are prepared using various metal and metal alloys. Most frequently, titanium and gold alloys are as used infrastructure materials. In addition, various chrome-cobalt (Cr-Co) alloys are preferred for their low cost and favorable mechanical properties[12].

Finite element analysis, which we used in our study, is a computer-based numerical solution method that can provide analytical solution to problems with complex geometries. Finite element analysis has become a frequently preferred method in dentistry in recent years thanks to its features, such as the ability to model all types of structures, the absence of limits on the number of materials used, the ability to obtain stress distributions and displacements together, the control of the experimental model and the ability to change the boundary conditions[13]

The aim of this study was to evaluate the stresses created on bone tissue, implants and bar holder as a result of occlusal loading by 3 implant-supported bar-holder mandibular overdenture prostheses designed with different vertical misfits, different distal extensions and different materials.

Material and Methods

A complete edentulous mandible was used for modeling. A bar-retained prosthesis model has been designed on three implants put at the places of both canines and in the midline. The distance between implants was modeled to be 12 mm. Implants (Straumann® SLActive®, Straumann AG, Basel, Switzerland) were designed with bone level tapered screw-retained flat abutments, placed parallel to each other and perpendicular to the occlusal plane. The implant in the middle of the mandibular arch was 3.3 mm in diameter, 10 mm in length, and the implants placed in the canine areas were 4.1 mm in diameter and 10 mm in length. Different models were made according to different vertical incompatibility, different distal cantilever length and different infrastructure materials, so 27 different models were defined (Table 1).

Table 1. Models of the study

Model	Bar material	Cantilever	Misfit
1	Titanium grade 5	0 mm	0 µm
2	Titanium grade 5	8 mm	0 µm
3	Titanium grade 5	14 mm	0 µm
4	Titanium grade 5	0 mm	100 µm
5	Titanium grade 5	8 mm	100 µm
6	Titanium grade 5	14 mm	100 µm
7	Titanium grade 5	0 mm	200 µm
8	Titanium grade 5	8 mm	200 µm
9	Titanium grade 5	14 mm	200 µm
10	Type 4 gold	0 mm	0 µm
11	Type 4 gold	8 mm	0 µm
12	Type 4 gold	14 mm	0 µm
13	Type 4 gold	0 mm	100 µm
14	Type 4 gold	8 mm	100 µm
15	Type 4 gold	14 mm	100 µm
16	Type 4 gold	0 mm	200 µm
17	Type 4 gold	8 mm	200 µm
18	Type 4 gold	14 mm	200 µm
19	Chrome - cobalt	0 mm	0 µm
20	Chrome - cobalt	8 mm	0 µm
21	Chrome - cobalt	14 mm	0 µm
22	Chrome - cobalt	0 mm	100 µm
23	Chrome - cobalt	8 mm	100 µm
24	Chrome - cobalt	14 mm	100 µm
25	Chrome - cobalt	0 mm	200 µm
26	Chrome - cobalt	8 mm	200 µm
27	Chrome - cobalt	14 mm	200 µm

The implants and prosthesis parts supplied in the study were scanned in 3D optical scanner (Activity 880 - Smart Optics, Sensortechnik GmbH, Bochum, Germany). The models obtained in stl format were sent to Rhinoceros 4.0 (Robert McNeel & Associates, Seattle, USA) 3D modeling software. With the Boolean method in Rhino software, harmonization was made between overdenture prosthesis, bar holder, implant abutments, implants and bone tissues. And then force transfer was achieved. An occlusal force of 150 N perpendicular to the occlusal plane was applied unilaterally at the central fossa of the left first molar tooth (Figure 1).

Elastic modulus (Young's modulus) and Poisson's ratio values of the material defining the physical properties of each of the structures that make up the models (Table 2) were defined referring to the relevant literature[14-18]. In the program, solid body properties were accepted as linear, elastic, homogeneous and isotropic.

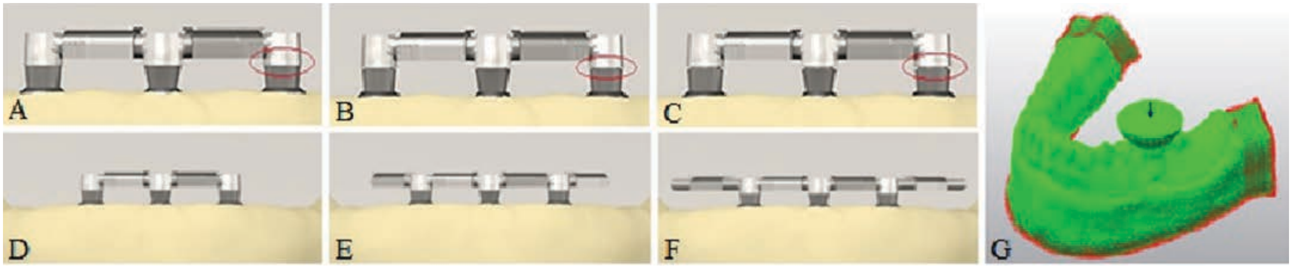

Figure 1. A: Misfit 0 µm, B: Misfit 100 µm, C: Misfit 200 µm, D: Bar cantilever 0 mm, E: Bar cantilever 8 mm, F: Bar cantilever 14 mm, G: Applying occlusal force

Table 2. Mechanical properties of the materials used in the study

Material	Structure	Young's modulus (MPa)	Poisson's ratio	References
-	Cortical bone	13700	0.30	Barão et al.[14]
-	Trabecular bone	1370	0.30	Barão et al.[14]
-	Mucosa	1	0.30	Topkaya and Solmaz[15]
Polymethylmethacrylate (PMMA)	Prosthesis base	3000	0.35	Topkaya and Solmaz[15]
Plastic	Overdenture clip	3000	0.28	Barão et al.[16]
Titanium grade-4	Implant,abutment	110000	0.33	Topkaya and Solmaz[15]
Titanium grade-5	Bar holder	110000	0.28	Caldas et al.[17]
Type- 4 gold	Bar holder	80000	0.33	Abreu et al.[18]
Chrome - cobalt	Bar holder	218000	0.33	Abreu et al.[18]

Table 3. Stress values observed in cortical bone, implants and bar holder (MPa)

	Maximum Principle Stresses Cortical bone			Minimum Principle Stresses Cortical bone			Von Mises Stresses Implants			Von Mises Stresses Bar holder*		
Model	Left posterior	Anterior	Right posterior	Left posterior	Anterior	Right posterior	Left posterior	Anterior	Right posterior	1*	2*	3*
1	0.86	2.76	0.71	-1.68	-1.97	-0,19	25.59	10.42	13.96	-	61.88	38.23
2	0.93	2.70	0.85	-1.86	-1.61	-0.08	26.99	11.77	7.21	0.75	59.20	39.71
3	0.25	0.48	1.07	-2.79	-0.67	-0.33	37.04	13.59	6.60	228.86	38.63	14.48
4	0.88	2.77	0.71	-1.68	-1.99	-0.19	24.90	10.84	13.99	-	58.20	32.47
5	0.95	2.71	0.86	-1.87	-1.62	-0.08	26.29	11.70	7.21	0.85	59.75	33.47
6	0.25	0.48	1.07	-2.78	-0.67	-0.32	36.69	13.32	6.67	228.72	43.17	14.63
7	0.88	2.76	0.72	-1.68	-1.99	-0.18	24.86	10.76	14.08	-	64.16	32.03
8	0.95	2.71	0.86	-1.86	-1.62	-0.08	26.27	11.92	7.25	0.92	64.18	40.69
9	0.25	0.48	1.07	-2.77	-0.67	-0.32	36.77	13.38	6.65	260.52	40.51	15.47
10	0.83	2.77	0.71	-1.68	-1.94	-0.17	26.78	10.85	14.70	-	56.67	36.48
11	0.90	2.72	0.85	-1.87	-1.59	-0.08	28.32	11.65	7.39	0.69	53.21	37.89
12	0.23	0.35	1.07	-2.53	-0.70	-0.32	32.03	13.10	6.82	194.59	38.44	17.17
13	0.85	2.78	0.71	-1.68	-1.96	-0.17	26.14	10.78	14.57	-	53.29	31.11
14	0.92	2.73	0.85	-1.88	-1.60	-0.08	27.68	11.89	7.38	0.76	54.21	31.85
15	0.23	0.35	1.07	-2.51	-0.70	-0.32	31.83	12.87	6.79	194.28	43.23	17.49
16	0.84	2.77	0.71	-1.68	-1.96	-0.17	26.11	10.70	14.68	-	58.51	30.71
17	0.92	2.73	0.85	-1.87	-1.60	-0.08	27.67	11.93	7.43	0.83	58.59	38.97
18	0.23	0.35	1.07	-2.51	-0.69	-0.32	31.91	12.92	6.83	222.87	41.16	18.59
19	0.90	2.65	0.73	-1.67	-1.97	-0.22	22.71	10.80	12.76	-	67.23	39.40
20	0.98	2.56	0.88	-1.84	-1.61	-0.08	23.88	12.15	6.79	0.88	67.44	40.83
21	0.29	0.85	1.07	-3.42	-1.06	-0.10	47.52	14.07	7.46	301.37	44.45	10.30
22	0.91	2.64	0.73	-1.67	-1.99	-0.21	21.97	10.75	12.61	-	66.01	32.70
23	0.99	2.55	0.88	-1.84	-1.61	-0.08	23.07	11.71	6.81	1.08	68.59	33.98
24	0.29	0.85	1.07	-3.39	-1.06	-0.32	46.66	14.05	7.57	300.00	48.65	10.96
25	0.97	2.63	0.73	-1.66	-1.98	-0.21	21.92	10.69	12.65	-	71.57	31.97
26	0.99	2.55	0.88	-1.84	-1.61	-0.08	23.07	11.75	6.84	1.17	73.24	41.77
27	0.29	0.85	1.07	-3.39	-1.07	-0.32	46.71	14.09	7.57	343.43	42.82	10.96

*** Selected joints in the bar holder:** 1* - Distal of the left posterior abutment; 2* - Mesial of the left posterior abutment; 3* - Left side of the anterior abutment

Results

In the cortical bone, the greatest maximum principle stress (σmax) was observed around the anterior implant socket in the model 13 (2.78 MPa). The lowest maximum principle stress was seen around the left posterior implant in the model 18 (0.23 MPa). With the increase in cantilever length, the highest stress values shift from the anterior implant to the terminal implant where force was not applied. Independent of the other two variables, when cantilever was 14 mm, the stress value in the cortical bone was highest in the right posterior implant. When the cantilever length and substructure were constant, the stress values in cortical bone with the increase of misfit changed similarly (Table 3).

In our study, the greatest minimum principle stress σmin in the cortical bone was analyzed around the left posterior implant in model 21 (-3.42 MPa), and the lowest minimum principle stress value was analyzed around the right posterior implant in model 14 (-0.08 MPa) (Table 3). Minimum principle stress values on the cortical bone increased parallel to the increase in cantilever length to the implant area where the force was applied. Minimum principle stress values in the cortical bone were similar in different vertical misfit and different bar holder materials (Table 3).

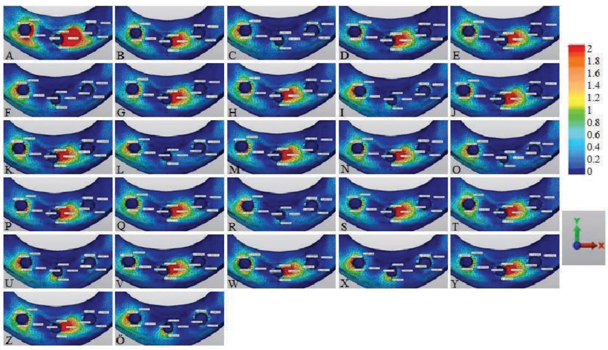

Figure 2. Tensile stresses (σmax) in cortical bone. A: Model 1, B: Model 2, C: Model 3, D: Model 4, E: Model 5, F: Model 6, G: Model 7, H: Model 8, I: Model 9, J: Model 10, K: Model 11, L: Model 12, M: Model 13, N: Model 14, O: Model 15, P: Model 16, Q: Model 17, R: Model 18, S: Model 19, T: Model 20, U: Model 21, V: Model 22, W: Model 23, X: Model 24, Y: Model 25, Z: Model 26, Ö: Model 27.

The greatest von Mises stress on the implants was observed in the model 21 on the left posterior implant (47.52 MPa), the lowest von Mises stress value was observed in the model 3 on the right posterior implant (6.60 MPa). When the forces on the implants were compared, the highest von Mises stress values were observed in the left posterior implant where the force was applied. With the increase in the amount of cantilever, von Mises stress values increased in the left posterior implant where the force was applied (Table 3). Bar holders made of chrome cobalt had higher stress values on the left posterior implant where the force was applied, compared to those made of other materials. Similar von Mises stress values in different vertical mismatches were analyzed. It has been observed that the forces were more concentrated in the neck area of the implants (Figure 3).

Figure 3. Von Mises stresses (σvM) on implants. A: Model 1, B: Model 2, C: Model 3, D: Model 4, E: Model 5, F: Model 6, G: Model 7, H: Model 8, I: Model 9, J: Model 10, K: Model 11, L: Model 12, M: Model 13, N: Model 14, O: Model 15, P: Model 16, Q: Model 17, R: Model 18, S: Model 19, T: Model 20, U: Model 21, V: Model 22, W: Model 23, X: Model 24, Y: Model 25, Z: Model 26, Ö: Model 27

The highest von Mises stress on bar holders was observed at the left-hand cantilever junction in the model 27 (343.43 MPa). Bar cantilever lengths of 14 mm groups were found to have very high stress values compared to groups without cantilever and 8mm cantilever. In the Cr-Co holder groups, higher stress values were observed in proportion to the elastic modulus of the bar holder material.

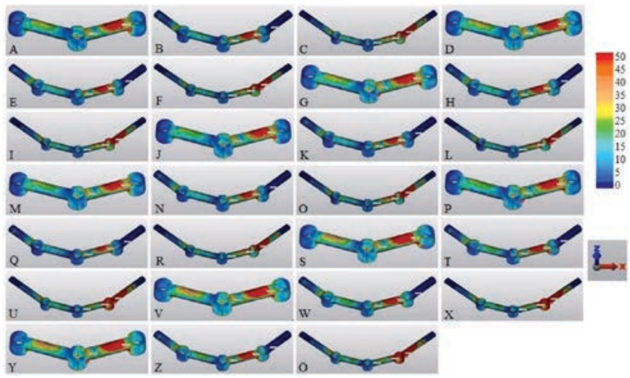

Figure 4. Von Mises stresses (σvM) formed in the bar substructure. A: Model 1, B: Model 2, C: Model 3, D: Model 4, E: Model 5, F: Model 6, G: Model 7, H: Model 8, I: Model 9, J: Model 10, K: Model 11, L: Model 12, M: Model 13, N: Model 14, O: Model 15, P: Model 16, Q: Model 17, R: Model 18, S: Model 19, T: Model 20, U: Model 21, V: Model 22, W: Model 23, X: Model 24, Y: Model 25, Z: Model 26, Ö: Model 27

Discussion

The long-term success of implant rehabilitation has been associated with passive fit between the implant and the prosthetic infrastructure. Initially Branemark identified a misfit of 10 μm as the tolerance limit[19]. However, in another study, it was stated that mismatches up to 150 μm were clinically acceptable[20]. Although these data are based empirically, there were no studies to replace or verify it. Generally, the misfit between prosthetic components is unavoidable due to many clinical and laboratory procedures involved in prosthetic construction, such as wax melting, casting, finishing, and polishing[21]. Some studies have shown that the presence of mismatch at the implant/ abutment interface induce the increased stress in the bone tissue around the implant and all prosthetic components[21,22].

In our study, we examined the stress distribution of different vertical misfits between abutment and bar holder on the bone, implants and prosthesis components. The stress values of different vertical mismatches on cortical bone were found to be similar. Carr *et al.*[23] in the study where they compared the stress values caused by two different incompatibilities, 38 μm and 345 μm in size did not find a significant difference in bone. Jemt and Book[24] in 1-year prospective and 5-year retrospective study shown that there was no correlation between 111 μm and maximum 275 μm infrastructure mismatch and marginal bone loss. Carr *et al.*[23] and Jemt and Book 's[24] results support the results of vertical mismatch in our study.

Different researchers have stated that the stiffness of the bar holder material affects the stresses on the supporting tissues and prosthetic components[18,21,25-27]. Abreu *et al.*[18] evaluated stress distributions of different bar substructure materials (gold alloy, silver-palladium, pure titanium, chromium-cobalt alloy) with 100 μm vertical mismatch in bone and prosthetic parts. Concerning the bar substructure, higher stress values were found in the screw neck and implant platform in the groups with higher hardness, mostly in the chromium-cobalt alloy group. Mochalski *et al.*[28] investigated the stress distribution under different loading conditions in the lower jaw-on-implant bar holders designed from chromium-cobalt, titanium and polyetherketonketone (PEKK) materials. The lowest values in the implant and bar holder were seen in the PEKK group. Caetano *et al.*[29], using finite element analysis examined the stress values of overdenture prostheses with bar retainers over two implants designed from different materials (Type 4 gold, silver-palladium, chromium-cobalt, titanium) on implants placed with different inclusions. As a result of their studies, the highest stress values were observed in bar holders made of chromium-cobalt alloy and the lowest stress values in those made of type-4 gold alloy. These results confirm the result of our study. In the harder bar material groups, higher stress values were obtained on implants and bar holder.

The maximum distal cantilever length is defined as the length that will not cause gold screw loosening or fatigue. However, without the distal cantilever extension, the prosthetic base had less retention and stability against delicate anatomical structures[30]. Elsyad *et al.*[31] examined the stress distribution in overdenture prostheses with bar retainers with 3 different distal extensions (7 mm, 9 mm, 11 mm) on 2 implants. The researchers recommended the use of 7 mm distal extension rods in implant-supported mandibular overdentures, because the lowest stresses were observed in the implant peripheral regions in this group.

In our study when the stress values in the bar infrastructure were examined, it was observed that the stress values in the 0 and 8 mm distal extension group followed each other at a certain rate, while a dramatic increase was observed in the stress value of the distal extension in the 14 mm group. We think that the reason for this result is the effect of increased leverage. The stress concentrated in the distal extension also increased the stress on the implant neck and cortical bone. The total stress of the system has increased. Designs in which stress is homogeneously distributed in mechanical parts and biological tissue should be preferred. When the stress amount and topographic distribution results of the designs with 8 mm extension are examined, it can be concluded that it can be a design that can be preferred in patients with distal extension.

Conclusions

Within the limitations of this finite element study, it can be concluded that:

1. von Mises values in the implant neck area have always been higher in the terminal implant where the force is applied. As a result of the increase of the framework distal extension, the von Mises value in the terminal implant increased;
2. on the bar holder, the higher von Mises values were seen in the bar framework models of the 14 mm distal cantilever extension;
3. bar attachments showed higher von Mises stress values as the hardness of the material increased. The highest stress values were in Cr-Co groups, the lowest values were in the type 4 gold groups;
4. there was no significant effect of vertical mismatch on stress values.

New studies should be conducted with different bar substructure sections, different numbers and diameters of implants, different degrees of vertical and horizontal incompatibility, different implant inclusions, new materials in prosthetic dentistry and their biomechanical properties. We also think that retrospective and prospective clinical studies on these issues would shed light in this field.

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