STRAIN EVALUATION OF PEEK CANTILEVER BARS AROUND IMPLANTS ASSISTED MANDIBULAR OVERDENTURES (IN VITRO STUDY)

Nada A. Abd El-Rahman [1*] BDS, Ahlam M. El-sharkawy [2] PhD, Mona H. Mohy El-din [3] PhD, Mona S. Saad [4] PhD

ABSTRACT

INTRODUCTION: Restoring the edentulous patient by an overdenture on splinted implants with cantilever bar can reduce the overload risk to every implant.
AIM OF THE STUDY: the aim of the study is to compare strain around implants assisted mandibular overdenture and on the ridge areas between metal and PEEK cantilever bar.
MATERIALS AND METHODS: 20 epoxy models were used. Two root form implants were placed bilaterally in the canine region of each edentulous epoxy mandibular model. 20 epoxy models were divided into 2 groups group A (control group) and group B (study group). For (Group A) the implants were connected with metallic cantilevered bar with 7.0 mm distal extension. For (group B) the implants were attached with PEEK cantilevered bar with the same distal extension length .Six linear strain gauges were connected around each implant and on the ridge areas. Strain values were measured under unilateral and central loading around the implants and on the ridge areas using a loading tool under (60 N) force. And the same measurements were repeated after 120,000 and 240,000 cyclic loading using cycling loading machine.
RESULTS: A statistically significant difference of strain values was found between the two groups before cyclic loading and after 120.000 and 240.000 cyclic loading. Metal cantilever bar showed higher strain values compared with PEEK cantilever bar ($p<0.001$).
CONCLUSION: PEEK cantilever bar exerts less strain and show favorable load distribution around the implants and on the ridge areas.
KEY WORDS: implant overdenture, PEEK, cantilever bar, strain

---

1 Bachelor of Dentistry, Faculty of Dentistry, Cairo University, Cairo, Egypt.
2 Professor of prosthodontics, prosthodontics department, Faculty of Dentistry, University of Alexandria, Alexandria, Egypt.
3 Professor of Dental Biomaterials, Dental Biomaterials Department, Faculty of Dentistry, University of Alexandria, Alexandria, Egypt.
4 Lecturer of prosthodontics, prosthodontics Department, Faculty of Dentistry, University of Alexandria, Alexandria, Egypt.

Corresponding author:
E-mail: nadaaladdin89@gmail.com

INTRODUCTION

Removable complete dentures are the least invasive and most cost-effective option for the prosthodontic rehabilitation of edentulous patients (1). Patients with the resorbed mandibular ridge often complain of lack of stability and retention of the mandibular denture. Therefore, the use of implant-stabilized dentures in the mandible has become common to improve patient satisfaction compared with conventional complete dentures (2).

Restoring the edentulous patient with an overdenture on 2 splinted or unsplinted implants may be considered the state of the art (3).

Implant-supported overdentures are supported only by the implants, either via a superstructure rigidly connected to them or directly with telescoping crowns (4). The least number of implants required for the mandible is four while for the maxilla 4-6 implants are required (5). The main gain is an improved allocation of occlusal forces amidst implant and bone which causes a decrease of alveolar ridge resorption (6).

Bar retained implant overdentures are an adequate treatment option for edentulous jaws as they constitute an outstanding anchorage structure that provides greater maintenance, allowing better force balance by its splinting effect and it can also rectify severe un-parallelisms (7).

Screw retained prosthesis have a well-documented history of successful application in completely edentulous patients. The major gain of screw- retained restorations is retrievability (8-9).

A cantilever length should be less than the space between implants to prevent overloads (10). It has been recommended that the used material for retaining-bar fabrication is highly significant for obtaining clinical success since it affects the biomechanics and propagation of stresses while functioning, which could be transferred to the bone-implant interface, implant, holding screws, and the bar itself (11).

Co-Cr, Ni-Cr alloys and Titanium are commonly used as scaffolds for the prosthetic bar production. However, they are poorly capable of absorbing and dissipating the stresses applied to the implants which increase the risk of losses (12).

The application of advanced materials and digital technologies has the potential to solve many of the problems surrounding oral health. Polyether ether ketone (PEEK), combines excellent physical properties, high temperature stability, and resistance to chemical damage, Furthermore, its elastic modulus is similar to that of the bone, it is biocompatible, bio-inert, and radiolucent (13-14).

Several in vitro techniques have been used to assess the biomechanical load on implant such as photo elastic, finite element and strain gauge analysis (15).

Accordingly the aim of this study was to evaluate the effect of two types of cantilever bar (metal and PEEK) on strain around two implants assisted mandibular overdenture and on the ridge areas by means of strain gauge analysis.

The null hypothesis is that the metallic cantilever bar and PEEK cantilever bar will have no differences regarding the strain around the implant and on the ridge areas.

MATERIAL AND METHODS

20 symmetrical epoxy edentulous mandibular models (Ramses Medical Factory, Alexandria) were used with mucosal pink silicon rubber material (Exahiflex, GC, Tokyo, Japan) of 2.5 mm in thickness was used to cover the epoxy resin to simulate the natural gingival mucosa.

Two Implants (Dentium, korea) of 4.0 mm diameter and 10.0 mm length were bilaterally placed by using hard acrylic clear vacuum formed drilling guide template with a hole through the guide template into the epoxy resin model corresponding to the position of the canine in both sides. (Fig1)

Two different cantilever bar materials were used in this study, so 20 epoxy models were divided into two groups:

Group A: (metal cantilever bar)

Two UCLA Plastic abutments (Dentium, korea) were modified with slight reduction occlusally and waxed up with open channel occlusally.

Ready-made plastic Hader bar (RHEIN 83, Italy keyhole cross-section) with 7.0 mm distal extension was connected to the wax coping and the space between bar and the ridge was 1.50 mm.

Conventional technique for casting Co-Cr metal alloy was done (Spruing, investing and casting), then finished and polished. (Fig 2)

Metallic cantilever bar screwed to the implants in the epoxy model.

Group B :(PEEK cantilever bar)

Two TI base metal abutments (dentium, korea.) were inserted and screwed over the two implants and were modified with slight reduction occlusally resembling the height of the metal abutment in the metal bar design.

Epoxy model (Ramses Medical Factory) with two TI- base abutment scanned by using extra oral scanner (InEos x5 extraoral scanner with robotic arm, dentsply, sirona ,USA) then cantilever bar designed with distal extension 7.0 mm in both sides bilaterally and with 1.50 mm space between bar and the ridge with open channel occlusally by using (DENTSPLY sirona in lab software)

PEEK disc (polyether ether keton, Brecam, bredent, Germany.) was milled by using Cutting Bur (2.5 PMMA) then finished and polished.

PEEK cantilever bar was bonded to metal abutment by using light-cured adhesive with chlorhexidine (0.2 %) (Peak TM Universal bond, Ultradent products , Germany) then screwed to the implants. (Fig 3)

Auto-mixed regular body vinyl polysiloxane (VPS) Impressions were made for the 20 epoxy models with cantilever bar and duplicated into stone casts by using vacuum mixed type III dental stone on which 20 identical mandibular overdenture were constructed using heat-polymerizing resin (Denture Base Material; Acrostone Co Ltd) by conventional standardized technique.

For direct pick-up of the clip into the overdenture base, the clip inserted at the center of the bar, the base of the denture corresponding to the cantilever bar was relieved with an acrylic bur until the denture can be fully seated passively on the model, a mix of soft liner (Soft liner, Acrostone ,Egypt) was made. The spaces were filled using a plastic filling instrument and seated under pressure for 4 minutes to allow for setting. The denture was removed and the clip was picked up in it. The excess material was removed and finished.

For strain analysis, Self-protected linear gauges (Koyoma Strain Gages, Japan) were used for this study; a gauge length was 1mm with a resistance of 119.6 ohm and a gauge factor was 2.13%. Eight strain gauges were used to monitor the effect of the applied load as they were installed as follows:

Two strain gauges were installed on mesial and distal sufraces of each implant.

One strain gauge was installed on the crest of the ridge corresponding to the mesial fossa of lower second molar bilaterally for each side.

The epoxy model (Ramses Medical Products Factory, Alexandria) was prepared to be suitable for strain gauges(Koyoma Strain Gages, Japan) installation. Small channels were prepared through the epoxy model from the base up to the mesial and distal surfaces of each implant and through the base of the epoxy model upto the crest of the ridge corresponding to mesial fossa of the lower second molar bilaterally. A strain gauge adhesive (CC-33A, EP-34B Strain Gagecement.) was used to cement the strain gauges at the selected sites.(Fig 4)

A custom made metal bar with occlusal imprints on the first molars was fabricated as a platform to receive the vertical load both centrally and unilaterally, small V-shaped grooves were created on the metal plate midpoint and at the first molar area at each side to locate the tip of the loading point accurately.

A universal testing machine (Multi Test5-XT; Mecmesin Corp) and strain meter (Data Logger model TDS-150 Manufactured by TML,Tokoyo, Japan.) were used. The model was attached to the lower member of the universal testing machine, The lead wires from each active strain gauge were connected to the strain meter.

Central and unilateral (right and left) vertical loads of 60 N at a constant rate (crosshead speed) of 10.0 mm/min. were applied on the previously prepared points on the metal bar. (Fig 5)

Once the load was applied, the obtained micro-strain readings were recorded by the strain meter which was connected to a personal computer with aiding of special software to allow for viewing the obtained microstrain readings. All measurements were repeated 5 times allowing at least 5 minutes for recovery and to allow for heat dissipation, and the mean of recorded micro- strain values were subjected to statistical analysis. For both groups the same steps were repeated.

After initial strain measurements all implants assisted overdenture were subjected to 120.000 cycles that mimic 6 months in patient mouth with vertical load of about 10N at a constant rate (crosshead speed) of 0.3 mm/min by using Cyclic loading machine (custom-made cyclic loading machine Faculty of Dentistry Alexandria University, Biomaterials Department), Custom made metallic bar with two horizontal bars (anterior and posterior bar), connected with metal plate in the center by means of screws. Anterior metal bar with occlusal imprints on the canines bilaterally, and posterior metal bar with occlusal imprints over the lower first molars was constructed to insert the load over the occlusal surfaces bilaterally. (Fig 6)

The epoxy model was placed on the lower custom made flat metal flask that was filled with putty rubber base material mixed with catalyst to act as Cushing material to avoid fracture of the epoxy model base during cyclic loading.

After that The epoxy model was re-placed on the lower flat metal plate of a universal testing machine (Multi Test5-XT; Mecmesin Corp) and seated between its two plates for strain measurement after 120.000 cycling loading ,and then central and unilateral (right and left) vertical loads were applied on the previously prepared points on the metal bar. The mean of recorded micro strain values were subjected to statistical analysis. For both groups the same steps were repeated.

The epoxy model was replaced again to the cycling loading machine (custom-made cyclic loading machine Faculty of Dentistry Alexandria University, Biomaterials Department), overdentures were subjected to another 120.000 cycles loading (=240.000 mimic one year in patient mouth) with vertical load of about 10N. Then the strain was measured by using universal testing machine (Multi Test5-XT; Mecmesin Corp) and strain meter (Data Logger model TDS-150 Manufactured by TML,Tokoyo, Japan.) and repeated the same as before for all models in each group

Statistical analysis of the data

Data were supplied to the computer and evaluated using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). The Kolmogorov-Smirnov test was used to verify the normality of distribution Quantitative data were described using range (minimum and maximum), mean, standard deviation, median and interquartile range (IQR). Significance of the obtained results was judged at the 5.0% level.

The used test was

1 - Student t-test

For typically distributed quantitative variables, to evaluate between 2 studied groups.

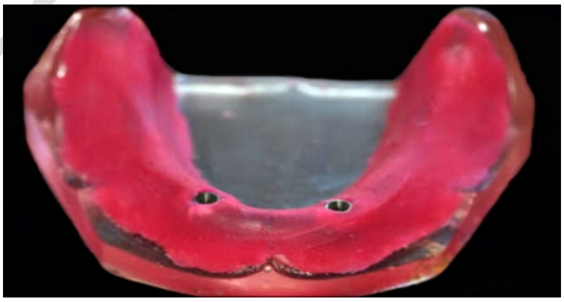

Figure 1: Epoxy model with 2 implants.

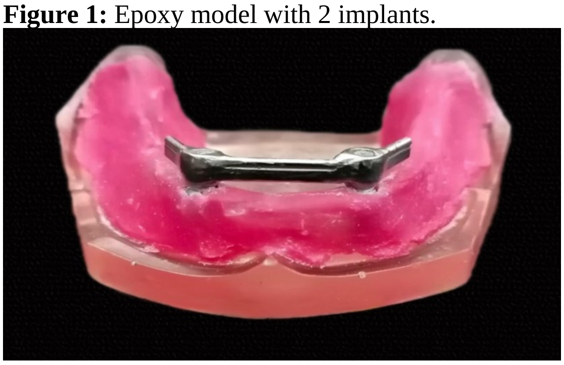

Figure 2: Two implants splinted with metallic cantilever bar.

Figure 3: Two implants splinted with PEEK cantilever bar.

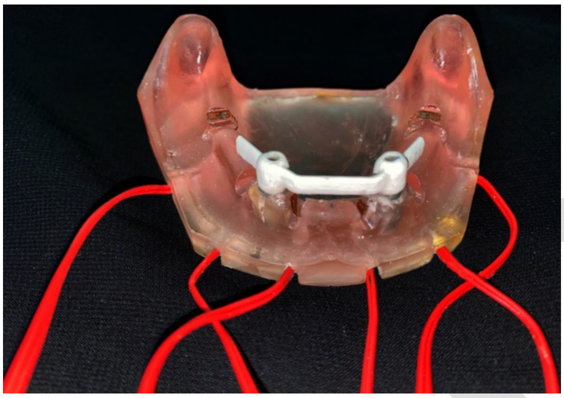

Figure 4: Installation of 6 strain gauges.

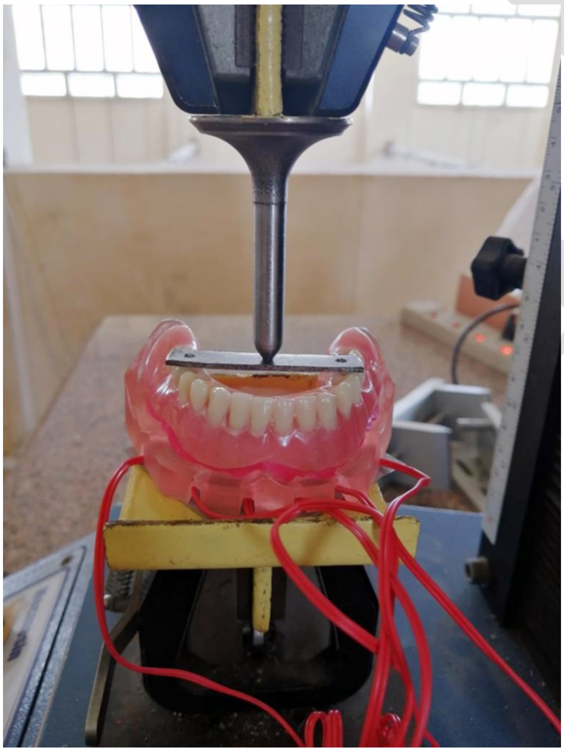

Figure 5: Application of vertical load of 60 N.

Figure 6: Application of cyclic loading of 10N.

RESULTS

Data were collected, tabulated and statistically presented as follows

A statistically significant difference was found between metal cantilever bar and PEEK cantilever bar as metal cantilever bar showed higher micro-strain values around the implants (mesial and distal) and on the ridge areas when load of 60 N was applied central and unilateral (right and left) on the metal bar while PEEK cantilever bar showed lower micro-strain values around the implants (mesial and distal) and on the ridge areas before cyclic loading ($p<0.001$). (Table 1)

After subjected to 120.000 and 240.000 cycling loading, A statistically significant difference was found as metal cantilever bar showed higher micro-strain values around the implants (mesial and distal) and on the ridge areas when load of 60 N was applied central and unilateral (right and left) on the metal bar while PEEK cantilever bar showed lower micro-strain values around the implants (mesial and distal) and on the ridge areas after cyclic loading ($p<0.001$). (Table 2)

Table 1: Comparing the two groups as regard strain on implants and alveolar ridge before cycling loading.

Cycle loading	Cantilever bars on strain	Group A (n = 10)	Group B (n = 10)	t	P
Before cyclic loading	Central				
	Right implant	11.97 ± 1.59	6.28 ± 1.24	8.896*	<0.001*
	Left implant	16.74 ± 1.83	7.25 ± 1.17	13.835*	<0.001*
	Right ridge	19.18 ± 3.03	12.17 ± 1.89	6.205*	<0.001*
	Left ridge	16.46 ± 4.37	12.83 ± 1.75	2.440*	0.025*
	Lateral left				
	Right implant	32.44 ± 5.03	12.64 ± 2.69	10.978*	<0.001*
	Left implant	48.14 ± 6.41	22.72 ± 3.57	10.948*	<0.001*
	Right ridge	10.73 ± 0.33	6.63 ± 0.51	21.498*	<0.001*
	Left ridge	65.32 ± 15.01	33.60 ± 3.63	6.497*	<0.001*
	Lateral Right				
	Right implant	33.87 ± 5.47	22.21 ± 3.14	5.848*	<0.001*
	Left implant	20.46 ± 4.70	11.97 ± 1.49	5.447*	<0.001*
	Right ridge	62.89 ± 11.89	33.36 ± 4.34	7.378*	<0.001*
	Left ridge	10.73 ± 0.33	6.63 ± 0.51	21.498*	<0.001*

Data was expressed using Mean ± SD.
t: Student t-test
p: p value for comparing between the studied groups
*: Statistically significant at $p \leq 0.05$

Table 2: Comparing the two groups as regard strain on implants and alveolar ridge after 120.000 and 240.000 cycling loading.

Cycle loading	Cantilever bars on strain	Group A (n = 10)	Group B (n = 10)	t	P
After 120.000 cyclic loading	Central				
	Right implant	37.95 ± 4.15	14.57 ± 4.39	12.228*	<0.001*
	Left implant	34.72 ± 8.36	21.93 ± 5.17	4.112*	0.001*
	Right ridge	45.97 ± 3.63	22.82 ± 5.16	11.598*	<0.001*
	Left ridge	64.21 ± 5.45	25.22 ± 7.02	13.880*	<0.001*
	Lateral left				
	Right implant	51.24 ± 7.72	21.72 ± 5.39	9.915*	<0.001*
	Left implant	74.35 ± 5.35	45.22 ± 5.64	11.855*	<0.001*
	Right ridge	15.82 ± 0.56	9.94 ± 0.76	19.787*	<0.001*
	Left ridge	99.35 ± 13.45	70.47 ± 6.92	6.038*	<0.001*
	Lateral Right				
	Right implant	64.39 ± 9.46	44.73 ± 5.02	5.806*	<0.001*
	Left implant	31.34 ± 6.41	15.99 ± 2.29	7.134*	<0.001*
	Right ridge	94.76 ± 17.85	79.30 ± 6.98	2.552*	0.026*
	Left ridge	15.82 ± 0.56	9.94 ± 0.76	19.787*	<0.001*
After 240.000 cyclic loading	Central				
	Right implant	43.20 ± 4.15	16.62 ± 4.39	13.902*	<0.001*
	Left implant	42.72 ± 8.36	24.53 ± 5.17	5.848*	<0.001*
	Right ridge	50.97 ± 3.63	24.82 ± 5.16	13.101*	<0.001*
	Left ridge	70.21 ± 5.45	27.72 ± 7.02	15.126*	<0.001*
	Lateral left				
	Right implant	59.14 ± 7.72	25.57 ± 5.39	11.276*	<0.001*
	Left implant	81.60 ± 5.35	51.97 ± 5.26	12.491*	<0.001*
	Right ridge	22.75 ± 2.27	17.75 ± 1.92	5.319*	<0.001*
	Left ridge	109.95 ± 12.01	82.47 ± 6.31	6.405*	<0.001*
	Lateral Right				
	Right implant	71.64 ± 9.46	52.78 ± 6.26	5.256*	<0.001*
	Left implant	38.97 ± 6.87	18.34 ± 2.29	9.000*	<0.001*
	Right ridge	104.28 ± 16.50	89.30 ± 8.11	2.577*	0.023*
	Left ridge	20.82 ± 0.56	11.94 ± 0.76	29.877*	<0.001*

Data was expressed using Mean ± SD.
t: Student t-test
p: p value for comparing between the studied groups
*: Statistically significant at $p \le 0.05$

DISCUSSION

Nowadays, splinted implants are accepted as means of support and to improve retention and stability of the mandibular overdenture, it is also claimed that splinting can prevent overloading (16).

Epoxy model was selected for the installation of implant as it has suitable elastic modulous for resembling bone material (approximately 20 GPa). To imitate the resiliency of soft mucosal tissue of the edentulous mandible, the surface of the model was covered by uniform layer of silicone based soft lining material (17).

Two implants with 10 mm length were chosen as it is considered as an adequate length to obtain optimum stress distribution around the implants according to Georgiopoulos et al (18).

Canine area was selected as Semper et al; 2010, elsyad et al; 2013 reported that the connection of canine implants with a cantilevered bar may decrease overdenture rotation during function, enhances the denture support, improve chewing, and reduce loading of denture bearing areas) (19-20).

Cantilever bar with 7mm distal extension was selected as El-Syad et.al reported that cantilever bar with 7mm length with clip recorded lowest peri-implant strain values than bars with 9mm and 11mm cantilever length (20).

A few researches indicated that PEEK may be utilized as an attachment preserving implant-supported overdentures. Its elastic modulus is like that of bone that may reduce the stress effects on peripheral bone (14).

Strain gauges were used for measuring strains due to their small size, linearity, and minimal interference during testing (21). The channels were prepared on the mesial and distal side of the implants as peak strains occur on the mesial and distal wall of the supporting bone around the implants, precisely opposite to the collar of the implants due to the rigid connection between the implant and bone (22-23). Bone loss usually initiated at the posterior ridge, so another channels were prepared on the crest of the ridge opposite to the lower second molar (24).

A magnitude of load 60.0 N was selected considering that the maximum forces applied by patients using complete dentures during mastication range between 60.0 N and 80.0 N (25).

The results of initial loading when the central and unilateral vertical loads were applied, it was found that the differences in micro strains values were statistically significant where metallic bar showed higher micro-strain values around the implants and on the ridge areas than PEEK cantilever bar. This result is due to PEEK has a high degree of load absorption and its elastic modulus is comparable to that of the bone (3–4 GPa) (14).

Others results are confirming the current study findings; since El- Anwar et al; reported that PEEK bar exhibited better stress distribution in implants compared to other metal groups including titanium (26) .

In addition, these study findings are consistent with the findings of Mochalski et al., study where the stresses in the implants and the bone bed around the implants displayed higher values under axial load with the Ti bar than with the PEEK bar (27).

However, the study was with in disagreement with Ehab M. Abd-Elhaleim., study that showed no statistically significant difference between (CoCr) bars and (PEEK) bars on stress distribution in implant supported mandibular overdenture supporting structure under unilateral and bilateral load application (28).

All overdentures were subjected to 120.000 load cycles of 10.0N to mimic 6 months clinical use and to Another 120.000 (=240.000 load cycles) to mimic one year clinical use (25).

In this study, load of 10N applied on the overdenture by using metallic bar fixed to the upper part of the load cycling machine as the masticatory force of completely edentulous patients is 20%–40% of that of healthy dentate persons as the average forces in dentate can range from 50-200 N (29).

The results in this study, a statistically significant difference was found between metal cantilever bar and PEEK cantilever bar as metal cantilever bar showed higher strain values around (mesial and distal) of the implants and on the ridge areas after(120.000 and 240.000) cycling loading than PEEK cantilever bar. These results may be because of the material's high resilience and the viscoelastic performance of PEEK, on which it absorbs more energy from applied load allowing effective dissipation of mastication loads this explanation was compatible with Xin chen et al., study that discussed PEEK mechanical behavior (30). Furthermore, it had good fatigue resistance and exhibited a low creep rate (13).

Based on the intensive review performed by the authors, no published data was found on the effect of cycling loading on the PEEK bar and the stresses transmitted around the implants or on the ridge areas.so we cannot compare the results with other studies.

The null hypothesis was banned because there was a significant difference between metal cantilever bar and PEEK cantilever bar on strain around the implants and on the ridge areas.

CONCLUSIONS

Centered on the outcomes of this in vitro study, the subsequent conclusions were made:

PEEK cantilever bar showed lower strain values around implants assisted mandibular overdenture (mesial and distal) and on the ridge areas under initial loading and after cycling loading than metal cantilever bar.

These findings can encourage the use of PEEK cantilever bar in oral rehabilitation with implant-assisted overdenture as it showed favorable load distribution.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

FUNDING

The authors received no funding for this work.

REFERENCES

1. Felton D, Cooper L, Duqum I, Minsley G, Guckes A, Haug S, et al. Evidence-based guidelines for the care and maintenance of complete dentures: a publication of the American College of Prosthodontists. J Prosthodont. 2011;20 Suppl 1:S1-S12.
2. Tymstra N, Raghoebar GM, Vissink A, Meijer HJ. Maxillary anterior and mandibular posterior residual ridge resorption in patients wearing a mandibular implant-retained overdenture. J Oral Rehabil. 2011;38:509-16.
3. de Jong MH, Wright PS, Meijer HJ, Tymstra N. Posterior mandibular residual ridge resorption in patients with overdentures supported by two or four endosseous implants in a 10-year prospective comparative study. Int J Oral Maxillofac Implants. 2010;25:1168-74.
4. Walton JN, MacEntee MI, Click N. One-year prosthetic outcomes with implant overdentures: a randomized clinical trial. Int J Oral Maxillofac Implants. 2002;17:391-18.
5. Timmerman R, Stoker GT, Wismeijer D, Oosterveld P, Vermeeren JI, van Waas MA. An eight-year follow-up to a randomized clinical trial of participant satisfaction with three types of mandibular implant-retained overdentures. J Dent Res. 2004;83:630-3.
6. Raedel M, Lazarek-Scholz K, Marré B, Boening KW, Walter MH. Posterior alveolar ridge resorption in bar-retained mandibular overdentures: 10-year results of a prospective clinical trial. Clin Oral Implants Res 2015;26:1397-401.
7. Dudic A, Mericske-Stern R. Retention mechanisms and prosthetic complications of implant-supported mandibular overdentures: long-term results. Clin Implant Dent Relat Res. 2002;4:212-9.
8. Abd El-Dayem MA, Assad AS, Eldin Sanad ME, Mahmoud Mogahed SA. Comparison of prefabricated and custom-made bars used for implant-retained mandibular complete overdentures. Implant Dent. 2009;18:501-11
9. Kim HY, Lee JY, Shin SW, Bryant SR. Attachment systems for mandibular implant overdentures: a systematic review. J Adv Prosthodont. 2012;4:197-203.
10. Vercruyssen M, Quirynen M. Long-term, retrospective evaluation (implant and patient-centred outcome) of the two-implant-supported overdenture in the mandible. Part 2: marginal bone loss. Clin Oral Implants Res. 2010;21:466-72.
11. Romanos GE, Gupta B, Eckert SE. Distal cantilevers and implant dentistry. Int J Oral Maxillofac Implants. 2012;27:1131-6.
12. Al Jabbari YS. Physico-mechanical properties and prosthodontic applications of Co-Cr dental alloys: a review of the literature. J Adv Prosthodont. 2014;6:138-45.
13. Qin L, Yao S, Zhao J, Zhou C, Oates TW, Weir MD, et al. Review on Development and Dental Applications of Polyetheretherketone-Based Biomaterials and Restorations. Materials (Basel). 2021;14:408.
14. Mangano F, Mangano C, Margiani B, Admakin O. Combining Intraoral and Face Scans for the Design and Fabrication of Computer-Assisted Design/Computer-Assisted Manufacturing (CAD/CAM) Polyether-Ether-Ketone (PEEK) Implant-Supported Bars for Maxillary Overdentures. Scanning. 2019;2019:4274715.
15. Corrêa CB, Ribeiro AL, Reis JM, Vaz LG. Photoelasticity in Dentistry: a literature review. RSBO Revista Sul-Brasileira de Odontologia. 2014;11:178-84.
16. Zou D, Wang F, Wu Y, Huang W, Zhang C, Zhang Z. Implant-Supported Telescopic Crown-Retained Overdentures for Oral Rehabilitation of Patients with Severe Bony Defects: A 5-Year Retrospective Study. Int J Oral Maxillofac Implants. 2015;30:937-44.
17. Al-Ahmad A, Masri R, Driscoll CF, von Fraunhofer J, Romberg E. Pressure generated on a simulated mandibular oral analog by impression materials in custom trays of different design. J Prosthodont. 2006;15:95-101.
18. Georgiopoulos B, Kalioras K, Provatidis C, Manda M, Koidis P. The effects of implant length and diameter prior to and after osseointegration: a 2-D finite element analysis. J Oral Implantol. 2007;33(5):243-56.
19. Semper W, Heberer S, Nelson K. Retrospective analysis of bar-retained dentures with cantilever extension: marginal bone level changes around dental implants over time. Int J Oral Maxillofac Implants. 2010;25:385-93.
20. Elsyad MA, Al-Mahdy YF, Salloum MG, Elsaih EA. The effect of cantilevered bar length on strain around two implants supporting a

mandibular overdenture. Int J Oral Maxillofac Implants. 2013;28:e143-50.

21. Tribst JP, Dal Piva AM, Rodrigues VA, Borges AL, Nishioka RS. Stress and strain distributions on short implants with two different prosthetic connections–an in vitro and in silico analysis. Braz Dent Sci. 2017 Sep 26;20(3):101-9.
22. Negm EE, Aboutaleb FA, Alam-Eldein AM. Virtual Evaluation of the Accuracy of Fit and Trueness in Maxillary Poly(etheretherketone) Removable Partial Denture Frameworks Fabricated by Direct and Indirect CAD/CAM Techniques. J Prosthodont. 2019;28:804-10.
23. Cho YE, Park EJ, Koak JY, Kim SK, Heo SJ, Park JM. Strain gauge analysis of occlusal forces on implant prostheses at various occlusal heights. Int J Oral Maxillofac Implants. 2014;29:1034-41.
24. Bahuguna R, Anand B, Kumar D, Aeran H, Anand V, Gulati M. Evaluation of stress patterns in bone around dental implant for different abutment angulations under axial and oblique loading: A finite element analysis. Natl J Maxillofac Surg. 2013;4:46-51.
25. Shala K, Tmava-Dragusha A, Dula L, Pustina-Krasniqi T, Bicaj T, Ahmedi E, et al. Evaluation of Maximum Bite Force in Patients with Complete Dentures. Open Access Maced J Med Sci. 2018;6:559-63.
26. El-Anwar MI, Aboelfadl AK. Comparing different bar materials for mandibular implant-supported overdenture: Finite-element analysis. Indian J Dent Res. 2019;30:716-21.
27. Mochalski J, Fröhls C, Keilig L, Bourauel C, Dörsam I. Experimental and numerical investigations of fracture and fatigue behaviour of implant-supported bars with distal extension made of three different materials. Biomedical Engineering/Biomedizinische Technik. 2020;1(ahead-of-print). DOI: 10.1515/bmt-2020-0157
28. Abd-Elhaleim E, Al-Sadaawey M, Ragab R. The Effect of Different Bar Materials on Stress Distribution in Implant Supported Mandibular Overdenture Supporting Structure.(An in-Vitro Study). Al-Azhar Dental Journal for Girls. 2018;5:101-9.
29. Fontijn-Tekamp FA, Slagter AP, Van Der Bilt A, Van 'T Hof MA, Witter DJ, Kalk W, et al. Biting and chewing in overdentures, full dentures, and natural dentitions. J Dent Res. 2000 79:1519-24.
30. Chen X, Mao B, Zhu Z, Yu J, Lu Y, Zhang Q, et al. A three-dimensional finite element analysis of mechanical function for 4 removable partial denture designs with 3 framework materials: CoCr, Ti-6Al-4V alloy and PEEK. Sci Rep. 2019;9:13975.