Future Dental Journal

Volume 9 | Issue 2 — Article 14

2023

Effect of Different Implant Materials on Stresses Transmitted to Peri-Implant Areas of Implant-Retained Mandibular Overdenture

Diaa Mohamed Zahran Future University in Egypt, Diaa.Zahran@fue.edu.eg
Future University in Egypt, Diaa.Zahran@fue.edu.eg

Aya Fawzy Associate Professor of Prosthodontics, Future University in Egypt, A.mohamed@fue.edu.eg
Associate Professor of Prosthodontics, Future University in Egypt, A.mohamed@fue.edu.eg

Salah Hegazy Professor of Prosthodontics, Faculty of dentistry, Mansoura University, salahhegazy2003@yahoo.com
Professor of Prosthodontics, Faculty of dentistry, Mansoura University, salahhegazy2003@yahoo.com

Sara M. Shabaan Lecturer at Removable Prosthodontic Department, Faculty of Oral and Dental Medicine , Badr University, Cairo, Egypt
Lecturer at Removable Prosthodontic Department, Faculty of Oral and Dental Medicine , Badr University, Cairo, Egypt, m-saroo@hotmail.com

Ahmed A.Elwahed Shaaban Associate professor of Prosthodontics, Future University in Egypt, ahmed.abdelwahed@fue.edu.eg
Associate professor of Prosthodontics, Future university in egypt, ahmed.abdelwahed@fue.edu.eg

Recommended Citation

Zahran DM, Fawzy A, Hegazy S, Shabaan S, Shaaban AA. Effect of Different Implant Materials on Stresses Transmitted to Peri-Implant Areas of Implant-Retained Mandibular Overdenture. *Future Dental Journal*. 2024; 9(2).

Effect of Different Implant Materials on Stresses Transmitted to Peri-Implant Areas of Implant-Retained Mandibular Overdenture

Abstract

Aim this in vitro study was conducted to evaluate the effect of mechanical loading on different implant materials on supporting structures **materials and methods:** a total of three implant retained overdentures were used in this study, retained by two implants each (Titanium, polyetheretherketon and zirconia) were placed in epoxy resin casts at the canine area using a surgical guide. Soft liner material was used at the distal extension area to mimic the soft tissues. Two linear strain gauges were bonded buccal and lingual to each implant to measure the peri-implant strains during unilateral and bilateral loading. **Results:** during bilateral loading the highest strain values were recorded with the PEEK implants, while the lowest strain values were recorded with the zirconia implants. During unilateral loading, the highest strain values in the loading side were also demonstrated with the PEEK implants, and the lowest strain values were observed with the zirconia implants.

Conclusion: within the limitations of this in vitro study, PEEK implants were found to transmit more occlusal stresses at the marginal bone area than titanium and zirconia implants, thus PEEK implants avoid stress shielding phenomenon and its subsequent disuse atrophy of bone.

Keywords: PEEK, Zirconia, Titanium, strain, modulus of elasticity, implant overdenture

Introduction

Edentulous patients usually faced problems with their mandibular denture mainly related to retention. Retaining the dentures using implants was found to be effective in reducing complaints related to unretentive denture. Treatment options depend on the amount of bone available, and number of implants placed. In the mandible, a count of only two implants can be used to support an overdenture, placed in the inter-foraminal area that is divided into five equal columns of bone between the mental foramina. A, B, C, D and E; with C being in the midline, B and D in the canine area and A and E being in the first premolar area(1). According to Wolff's law, bone will be stimulated by load, within its physiological limits, and adapt to it (2). Also, the opposite is true, the bone density and strength decrease over the decrease of strain because of the lack of stimulation. So, density and strength decrease after an implant or a prosthesis is placed due to the transfer of stresses, at crestal bone, to them instead of the bone in a phenomenon called stress shielding. Stress shielding phenomenon occurs due to high difference modulus of elasticity. Titanium has a 110 GPa modulus of elasticity, while that of the human bone is 14 GPa; Polyetheretherketone (PEEK) has an elastic modulus of 12 to 18 GPa (2), while zirconia's modulus of elasticity of 210 GPa (3). The peri-implant strain can be measured using the strain gauges, which are small electric resistors that adjust the resistance created in their current during slight deformation of the object where they are placed. The generated electrical signals are then sent to a board for data acquisition and read by a computer (4). They are capable of recording the deformation of any material exposed to stresses and thus can be used to measure stresses in implants and their surrounding structures. The use of a strain gauge to evaluate the stresses presented clinical reliability, either if used alone or along with either the photoelastic analysis or the finite element method.

Materials and methods

Fabrication of the test model and overdentures:

The study was conducted on clear epoxy resin casts. To fabricate the models, an impression of a completely edentulous mandibular ridge using addition silicone rubber base. After pouring of the cast, undesired undercuts were blocked out and a silicone mold was made to ensure standardization of the arch and ridge shape of the models. The silicone mold was then prepared for the fabrication of the model casts by painting a thin layer of Vaseline to act as separating medium for easy removal of the epoxy model after its setting. A mix of clear epoxy resin was prepared according to manufacturer instructions and used to fill the silicone mold. The process was repeated similarly for the three casts. The stone cast was then sprayed using Renfert scan spray and scanned using a desktop scanner (Medit t710). A digital wax-up prosthesis was used to overlap the surgical guide to relate the implant positions to the canine area (5)Figure **1**. The digital copy of the cast was used to fabricate surgical guide to ensure standardization of positioning and parallelism of implants Figure **2** The designed surgical guide was then 3D printed by a 3D printer (Phrozen, Sonic mini 4k) using clear acrylic resin (6). Then, the implant that was planned to be used was also chosen during the designing process.

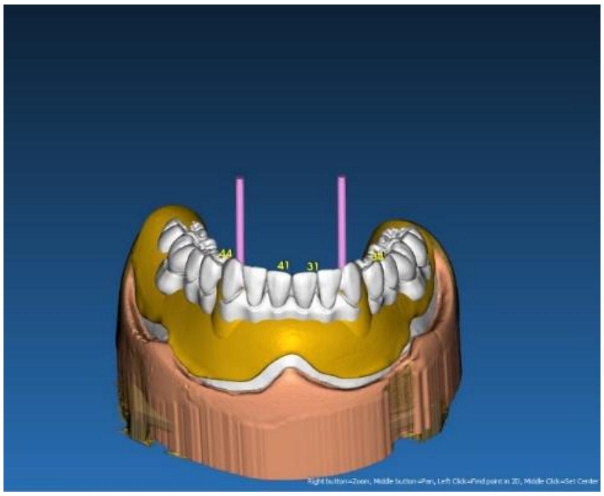

Figure 1 Determining the positions of the implants.

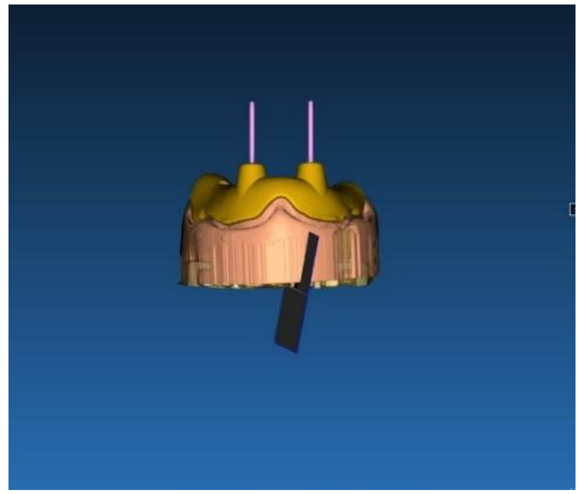

Figure 2 Checking the parallelism of the implants.

A digital copy of the titanium implant (Implant direct, USA) was made using Solidworks SP5 software with similar dimensions to the titanium one, 3.7 mm in diameter and 11.5 mm in length **Figure 3**. Using a five-axis milling machine (ED5X, Emar Mills, Egypt) two identical implants made from zirconia (Y-TZP) and another two made from PEEK were milled **Figure 4** so that their design would be the same and does not affect stress distribution (7). After that the surgical guide was used to place the six implants in their respective positions.

Figure 3 Digital copy of the titanium implant.

Figure 4 Milled zirconia and PEEK implants.

A new mix of clear epoxy resin was used to fix the implants in the casts to simulate the process of osseointegration. After that, soft liner material of 2 mm thickness was packed at the distal extension to simulate the soft tissues(8) Figure 5. An impression was then made for each cast using an addition silicone rubber base to obtain a cast on which an overdenture was fabricated, with the level of occlusal plane set to two-thirds the height of the retromolar pad.

Figure 5 Soft liner material used as a soft tissue mimic.

Strain gauge analysis

Fixation of strain gauges:

To get an idea about the stresses presented around the implants to the surrounding bone, the strain caused in the epoxy resin could be measured using strain gauge (4). Two linear strain gauges (KFG-1-120C1-11, Kyowa Electronic Instruments; Resistance 120.2 ±0.2 Ω, gauge length 1 mm; gauge factor 2.11 ±1.0%) were attached near the crest of ridge at the buccal and lingual surfaces related to each implant using a Cyanoacrylate adhesive to measure the peri-implant strains during loading (9)Figure 6. The long axis of each gauge was oriented with the long axis of the implants. The wires of the gauges were securely taped to both the buccal and the lingual surfaces of the epoxy resin casts. Each gauge was separately wired into a ¼ bridge of a multichannel digital bridge amplifier (Tinsley Precision Instrument, Model 8692).

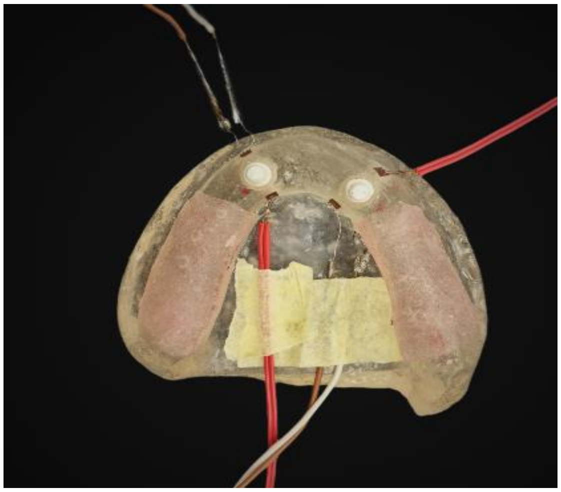

Figure 6 Strain gauge fixation

Strain gauge measurements

Using a universal loading machine (Lloyd LRX, Lloyd instruments) vertical static loads were applied to the occlusal surface of the implant-retained overdentures. Loads were applied bilaterally and unilaterally. A unilateral load was applied using an I-shaped load applicator, applying the load on the right side of the overdenture considering this side as the loading side and the other side (the left side) as the non-loading side Figure **7**. Application of bilateral load was applied on both the right and the left side using a T-shaped load applicator Figure **8**.

An occlusal notch in the central fossa of the first molar was used as a point of loading for both the unilateral and the bilateral load. an average level of biting force of denture wearer (50 N) was applied (10,11). Strains induced in the surrounding area of the implant at both the buccal and the lingual surfaces were measured during the application of load, unilaterally and bilaterally. The tests were repeated three times for each cast with an interval of five minutes between them for recovery. The values of the recorded strain were then exported to statistical analysis.

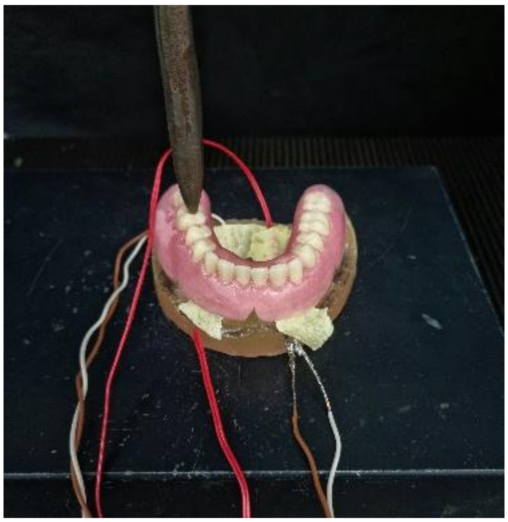

Figure 7 Unilateral load application.

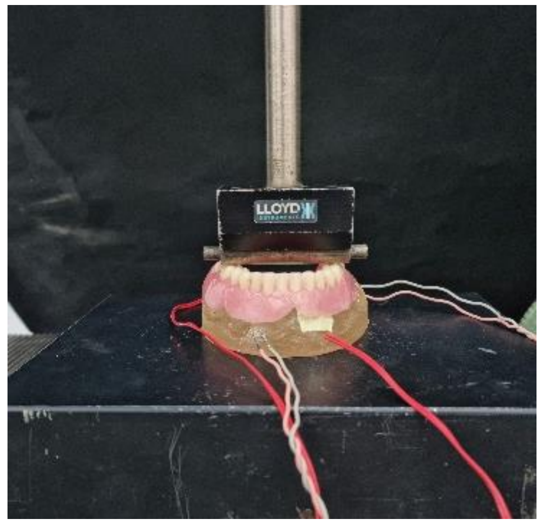

Figure 8 Bilateral load application.

Statistical analysis

Data were statistically described in terms of mean ± standard deviation (± SD). Because the groups are large enough, comparison between the study groups was done using One Way Analysis of Variance (ANOVA) test with Tukey's posthoc multiple 2-group comparisons. Two-sided p values less than 0.05 was considered statistically significant. IBM SPSS (Statistical Package for the Social Science; IBM Corp, Armonk, NY, USA) release 22 for Microsoft Windows was used for all statistical analyses.

Results

During bilateral load application

Strain values of buccal aspect of PEEK and zirconia were lower than strain values of lingual aspect of them, respectively, while in titanium, Buccal aspect showed higher strain values than that of lingual aspect. For bilateral application of load, the overall strain values showed a **highly significant difference** between PEEK and titanium implants (p-value < 0.001), and PEEK and zirconia implants (p-value < 0.001), while overall strain values showed **a significant difference** between titanium and zirconia implants (p-value 0.004). The highest values of stresses transmitted to supporting structures, represented in strain values, were recorded with PEEK implants, and the lowest strain values were recorded with zirconia (Table 1).

Table 1 Comparison of microstrains during bilateral loading.

Bilateral Loading	**(I)**	**(J)**	**Mean diff. (I-J)**	***p* value**
Overall	PEEK	Titanium	82.73	0.000*
	PEEK	Zirconia	112.72	0.000*
	Titanium	Zirconia	29.987	0.004*

Significance level p≤0.05, *significant

During unilateral load application

Strain was measured for each implant on buccal and lingual aspects of it, and values were recorded. In PEEK, buccal aspect at the loading side showed higher strain values than lingual aspect, also buccal aspect at the non-loading side showed higher values than lingual aspect. While in titanium, strain values were lower in buccal aspect at the loading side than in lingual aspect, and higher values were recorded in buccal aspect of non-loading side than that of lingual aspect. In zirconia, buccal aspect at loading side showed higher values than lingual side, and higher values in buccal aspect at non-loading side than its lingual aspect. The overall strain values, at the loading side, showed **a highly significant difference** between loading side of PEEK and titanium (p-value < 0.001), and between PEEK and zirconia (p-value < 0.001), and **a non-significant difference** between titanium and zirconia (p-value 0.636)Table 2. The highest strain values at the loading side were recorded with PEEK implants. The lowest strain values at the loading side were recorded with zirconia implants, while titanium implants showed strain values that are closer to that of zirconia implants, but higher. Strain values of the non-loading side showed a **highly significant difference** between PEEK and titanium (p-value < 0.001), and between PEEK and zirconia (p-value < 0.001), and **a non-significant difference** between titanium and zirconia (p-value 0.911) Table 3. The highest strain values were recorded with PEEK implants, and the lowest strain values were recorded with titanium implants, while zirconia implants showed a value close to that of titanium, but higher.

Table 2 Comparison of microstrains at the loading side during unilateral loading.

Loading side		Mean difference. (I-J)	p-value
(I)	(J)		
PEEK	Titanium	106.19	0.000*
PEEK	Zirconia	118.84	0.000*
Titanium	Zirconia	12.64	0.636

Significance level p≤0.05, *significant

Table 3 Comparison of microstrains at the non-loading side during unilateral loading.

Non-Loading side		**Mean difference. (I-J)**	**p-value**
(I)	**(J)**		
PEEK	**Titanium**	104.54	0.000*
PEEK	**Zirconia**	102.78	0.000*
Titanium	**Zirconia**	-1.75	0.911

Significance level p≤0.05, *significant

Discussion

The load transferred to the peri-implant area and the surrounding bone depends on loading type, prosthesis type and the type of attachment used. Also, the number and distribution of the implants influence the load transferred from implants to supporting structures(12). Despite having a long-term clinical success of telescopic attachment for two-implant retained mandibular overdenture, a study showed that a two-implant-retained mandibular overdenture, held in place with a rigid telescopic coping, would act like a firm, unbending lever, exerting a considerable force, which would be transferred from the implant to the surrounding bone(13). The results of this study, during bilateral load application, revealed that the lingual surface of the non-metallic implants showed higher strain than the buccal side. This can be attributed to the cantilever action of the denture distal saddles caused by resiliency of mucosal mimic when load was applied occlusally, creating a lever action where the lingual side acted as a fulcrum(14). The implant overdenture tended to hinge and rotate around the anteriorly positioned implants (in the inter-foraminal area) when posterior loading is applied. The results also showed least peri-implant strain values when zirconia implants were used in canine area compared to PEEK implants and titanium implants. This could be attributed to the higher modulus of elasticity of Y-TZP zirconia (3), providing the highest stress shielding effect on the crestal part. Therefore, its use would lead to greatest marginal bone loss among the tested materials, secondary to the disuse atrophy of the bone. In contrast, highest strain values were found with the Polyetheretherketone (PEEK) implants, either as an overall or on buccal or lingual sides. These findings can be attributed to the low elastic modulus of PEEK material, making its value closer to the surrounding structures(15). On the other hand, titanium implants showed low values of strain although being higher than those of zirconia implants, they still are significantly lower values than those of PEEK implants, highlighting its stress shielding effect attributed to its considerably high modulus of elasticity(16). During unilateral loading, implants on loading side showed higher values of strain than those on the non-loading side. These results came in agreement with various in vitro studies using strain gauge (9,17) and may be attributed to the implants location being near the side of the load application. PEEK implants did not show a high difference between loading side and non-loading side, this may be attributed to its low modulus of elasticity that gives it resilience(15). While strain values in loading side of PEEK implants showed a highly significant difference with both titanium and zirconia implants, and this agreed with their difference in stress shielding effect credited to their modulus of elasticity. While titanium implants showed a non-significant difference with zirconia implants in both loading and non-loading sides, this can be attributed to their higher modulus of elasticity than the surrounding structures(9,18).

The limitations of this study included absence of non axial application of load which may happen during masticatory process leading to change in direction of the occlusal forces causing different pattern of peri-implant stresses, absence of strain measurements at the mesial and distal peri-implant sites due to limited area as it would have recorded strain over wide area and not at the crestal region around the neck of the implant, absence of different types of epoxy resin to simulate different quality of bone and as in other in vitro studies, the gained data from strain gauge analysis is usually descriptive only as properties of epoxy resin do not simulate the complex nature of living bone.

Conclusion

Within the limitation of this in vitro study, the following conclusion can be drawn, titanium implants despite not showing the lowest strain values among the three materials compared, they still showed low strain level that marks its stress shielding effect. Polyetheretherketone (PEEK) implants showed the highest peri-implant strain levels compared to titanium or zirconia implants, thus avoiding the stress shielding problem encountered with other materials. zirconia implants, without modifications as in zirconia-based alloys, showed the lowest peri-implant strain compared to PEEK and titanium implants, and thus having the greatest stress shielding effect that would lead to disuse atrophy of the bone.

Refereneces

1. Misch CE. Resnik R. Misch's contemporary implant dentistry e-book. In: Contemp Implant Dent. 2020. p. 568–79.

2. Mishra S, Chowdhary R. PEEK materials as an alternative to titanium in dental implants: A systematic review. Vol. 21, Clinical Implant Dentistry and Related Research. Blackwell Publishing Ltd; 2019. p. 208–22.

3. Lucas TJ, Lawson NC, Janowski GM, Burgess JO. Effect of grain size on the monoclinic transformation, hardness, roughness, and modulus of aged partially stabilized zirconia. Dent Mater. 2015;31(12):1487–92.

4. Pesqueira ARA, Goiato MC, Filho HG, Monteiro DR, Dos Santos DM, Haddad MF, et al. Use of stress analysis methods to evaluate the biomechanics of oral rehabilitation with implants. J Oral Implantol. 2014;40(2):217–28.

5. Patil PG, Seow LL. Correlation of implant position and crestal bone loss in 2-implant mandibular overdentures with immediate loading protocols: A prospective clinical study. J Prosthet Dent. 2022;(August):1–8.

6. Anadioti E, Kane B, Zhang Y, Bergler M, Mante F, Blatz MB. Accuracy of Dental and Industrial 3D Printers. J Prosthodont. 2022;31:30–7.

7. Houshmand B, Ardakani MT, Moscowchi A, Oskoui IZ. Effect of Implant Design on Stress Distribution: A Finite Element Study. J Long Term Eff Med Implants. 2022;32(4).

8. Abou Warda DA, Sharkawy A, Abdel Hakim AA, Alabbassy FH. Evaluation of strain around labially inclined implants retaining mandibular overdentures with Titanium-silicone attachments (comparative in-vitro study). Alexandria Dent J. 2023;48(1):181–7.

9. Abo Elezz M. effect of different implant numbers and locations on strains around implants retaining mandibular overdentures with locator attachments. An in vitro strain gauge analysis. Egypt Dent J. 2022;68(3):2679–90.

10. Meyer JD. In-vitro-und In-vivo-Messungen der statischen und dynamischen Okklusion in der Totalprothetik. das J der Univ Göttingen. 2023;

11. Elsyad MA, Elsaadawy MG, Abdou AM, Ali Habib A. Effect of different implant positions on strain developed around four implants supporting a mandibular overdenture with rigid telescopic copings. Quintessence Int (Berl). 2013;44(9).

12. Tokuhisa M, Matsushita Y, Koyano K. ln Vitro Study of a Mandibular Implant Overdenture Retained with Ball, Magnet, or Bar Attachments: Comparison of Load Transfer and Denture Stability. Int J Prosthodont. 2003;16(2).

13. Krennmair G, Seemann R, Weinländer M, Piehslinger E. Comparison of ball and telescopic crown attachments in implant-retained mandibular overdentures: a 5-year prospective study. Int J Oral Maxillofac Implants. 2011;36(3).

14. Misch CE. The Edentulous Mandible: An Organized Approach to Implant-Supported. Contemp Implant Dent. 2008;29(3):45–8.

15. Papathanasiou I, Kamposiora P, Papavasiliou G, Ferrari M. he use of PEEK in digital prosthodontics: A narrative review. BMC Oral Health. 2020;20:1–11.

16. Elsyad MA, Setta FA, Khirallah AS. Strains around distally inclined implants retaining mandibular overdentures with Locator attachments: an in vitro

study. J Adv Prosthodont. 2016;8(2):116–24.

17. Alameldeen HE, Elsyad MA, Shawky AF KA. The Influence of Implant Inclination on Retention and Periimplant Stresses of Stud-Retained Implant Overdentures During Axial and Nonaxial Dislodgments: An In Vitro Study. Int J Oral Maxillofac Implant. 2020;50:35–543.

18. Ondruschka B, Hang J, Lee C, Scholze M, Zwirner J, Tong D, et al. A biomechanical comparison between human calvarial bone and a skull simulant considering the role of attached periosteum and dura mater. 2019;1603–10.