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Effect of Horizontal Cantilever on Microgap and Microleakage Through the Implant-Straight Abutment Interface in Cement-Retained Crowns

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Abstract

Background and Aim: This study aimed to assess the effect of horizontal cantilever on microgap and microleakage at the implant-straight abutment interface in cement-retained crowns.

Materials and Methods: In this experimental study, 12 implant-abutment assemblies and 12 cement-retained crowns were evaluated. The implant fixtures were bone-level, and had 10 mm length and 4 mm diameter. Straight titanium abutments had 7 mm length, 4 mm diameter, and 1 mm gingival height with Morse-Taper connection. Two groups were evaluated: 6 cement-retained crowns with a horizontal cantilever (test group) and 6 cement-retained crows without a horizontal cantilever (case group). The assemblies underwent load cycling in a chewing simulator. Cyclic load (75 N) with 1 Hz frequency was applied along the longitudinal axis of each specimen to the triangular ridge between the mesiobuccal and mesiolingual cusps of the crown. The amount of microgap before and after cyclic loading, and the microleakage score after immersion in fuchsine were evaluated under a light microscope. Data were compared by t-test (alpha=0.05).

Results: The change in microgap after cyclic loading compared with before was not significant in the control group (P=0.724). However, in the case group, the amount of microgap significantly increased after cyclic loading compared with before (P=0.000). Microleakage in the case group was significantly greater than that in the control group (P=0.019).

Conclusion: Horizontal cantilever caused horizontal microgap and increased the microleakage at the implant-straight abutment interface.

Key Words: Dental Implants, Single-Tooth; Dental Implant-Abutment Design; Dental Leakage

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Introduction

Evidence shows that stress concentration in implants supporting a cantilever is higher than that in implants without a cantilever. Also, it has been reported that stress is mainly concentrated in alveolar bone crest [1]. Dental implants are commonly used for replacement of the lost teeth. They are also used with cantilever systems [1]. Implant-supported cantilever prostheses include one or several implant abutments at one side and a pontic with no support at the other side. The first rule in key implant positions is not to design any cantilever in prosthesis [2]. Cantilevers create a wedge arm and inappropriately increase the load applied to the implants, implant abutments, cement, and implant-bone contact. However, in some clinical scenarios, application of cantilever is the most conservative treatment option, as in cases with inadequate bone volume in the posterior regions, esthetic considerations, dental crowding and misaligned teeth, failed implants, or poor quality of bone [2,3].

The mean amount of crestal bone loss around the neck of a functional implant is approximately 1 mm in the first year of placement and 0.1 mm annually in the next years [4]. Two factors causing crestal bone loss around dental implants include implant supporting tissues and traumatic forces that cause stress accumulation in the bone-implant complex exceeding the tolerable threshold [5]. Higher level of stress and tension has been reported in implants supporting a cantilever compared with those supporting non-cantilever restorations [5,6]. However, some other studies reported clinical success of implant-supported cantilever restorations, and showed their comparable function to non-cantilever restorations [3,4].

Failure of single implants in the posterior region has been commonly reported since they are under constant masticatory forces. Screw loosening and subsequent development of microgap at the implant-abutment interface is still a common problem in dental implant treatment [5-10]. Donley and Gillette [11] were the first to discuss the possibility of penetration of microorganisms in this region. Microgaps at the implant-abutment interface can have two types of consequences: (I) biological problems such as peri-implantitis and peri-implant mucositis, crestal bone loss, and oral malodor, and (II) mechanical complications such as abutment screw loosening and fracture, abutment fracture, and implant body fracture [5,9,10,12]. Factors affecting microgap and microleakage at the implant-abutment interface include the type of implant system, the geometry of the implant-abutment connection, use of custom-made abutments, applied torque for abutment tightening, and use of screw-retained instead of cement-retained abutments [13,14]. Several techniques have been suggested to minimize the risk of screw loosening and subsequent development of microgap and microleakage in implant-supported restorations such as absence of cantilever, centric occlusal contacts, correct preload of screws, narrow occlusal table, and flattening of the cuspal slope [5-8,11]. A number of studies have evaluated the formation of microgap, mechanical and biological failures, and effects of dynamic loading on microgap formation in dental implant restorations [13,14]. However, information regarding the relationship of cyclic loading and formation of microgap and subsequent microleakage through the implant-straight abutment interface in presence of horizontal cantilever crowns is limited. Thus, this study aimed to assess the effect of horizontal cantilever on microgap and microleakage at the implant-straight abutment interface in cement-retained crowns after cyclic loading. The null hypothesis was that there would be no significant difference in horizontal microgap and microleakage at the fixture-straight abutment interface after cyclic loading in the two groups of restorations with and without a cantilever.

Materials and Methods

This in vitro, experimental study was conducted on 12 implant-abutment assemblies and 12 cement-retained crowns. The present study was ethically approved by the Research Council, Dental Faculty of Islamic Azad University. The sample size was calculated to be 6 in each group according to a previous study [15] assuming the mean standard deviation of 1.8, minimum significant difference of 3 units, alpha=0.05, and beta=0.2

using Minitab software.

The implant abutment connection type was internal hexagon (Biogenesis Co., Seoul, Korea) [16]. Twelve straight abutments with 7 mm height, 1 mm gingival height, and 4 mm diameter, and 12 titanium dental implants with 10 mm length and 4 mm diameter were used in this study.

First, a high-speed drill was used to create four holes at four sides of each implant platform for further assessments [17]. Next, the implants were mounted in resin blocks with 19 mm length and 34 mm diameter to 1 mm distance from the implant platform [18]. The resin had a modulus of elasticity of 12 GPa, which is similar to the modulus of elasticity of bone (13.7 GPa) [19]. A dental surveyor (J.M. Ney Co., Bloom field, CT, USA) was used for higher accuracy in vertical mounting of implants in the acrylic blocks [20]. The abutments were tightened to 30 N/cm torque as recommended by the manufacturer using a digital torque meter (Lutron Electronic Enterprise Co, Taiwan) [21]. After 10 minutes, all abutments were retorqued to 30 N/cm to achieve optimal preload [14,22].

To assess the microgap at the implant-abutment interface, the assemblies were directly observed under a stereomicroscope (NSZ810; Novel, China) at x75 magnification [17]. The size of microgap was measured before and after cyclic loading.

The assemblies were then coded 1 to 12, and two reference points were marked. The upper reference point was the most inferior point of the abutment while the lower reference point was the most superior point of the implant fixture. Prior to cyclic loading, three photographs were obtained from the fixture-abutment interface at each of the four points marked on the implant platform (every 90-degree angle) under a stereomicroscope at x75 magnification, and the distance between the two reference points was measured [23].

Two abutments were placed on two fixtures. On one abutment, the wax pattern of mandibular first molar was waxed-up. In the control group, the central fossa was in line with the internal connection of the fixture. On the other abutment (test group), the wax pattern of a mandibular first molar was waxed-up such that its mesial marginal ridge had 5.5 mm distance from the mesial border of the fixture. The occlusal surface of both wax patterns was the same with a mesiodistal width of 11 mm, buccolingual width of 7 mm, and occlusogingival height of 11 mm (Figure 1)

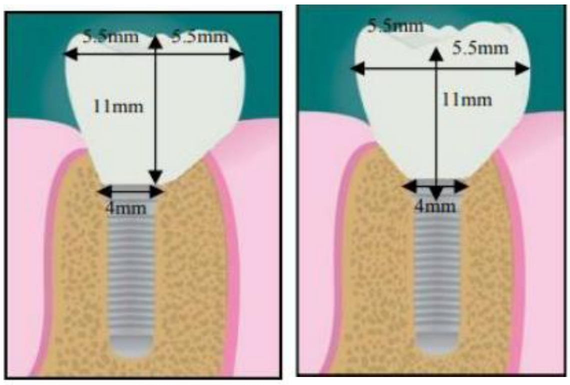

Figure 1. Schematic view of the two wax patterns

[24]. Next, the two waxed-up patterns were scanned for the purpose of standardization of restorations in terms of height, thickness, length, and diameter, and two resin patterns (Figure 2) were fabricated by a computer-aided design/computer-aided manufacturing system (CAD/CAM; IDC INTEGRATEDENTAL CAD/CAM, Austria).

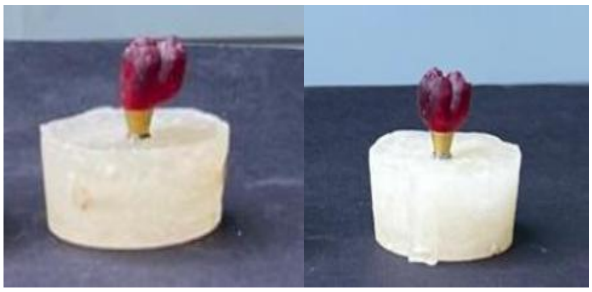

Figure 2. Resin patterns fabricated by the CAD/CAM technology

The resin patterns were then scanned for the purpose of standardization, and the restorations were fabricated by the CAD/CAM technology using nickel-chromium base-metal alloy (Minaluxe; Iran) [18]. All fabricated restorations were radiographically (X-Mind unit DC, Korea) assessed to ensure complete seating and adaptation of abutments. All restorations had complete adaptation. The abutment screws were torqued to 30 N/cm by an electric torque wrench [18,23]. After 10 minutes, they were retorqued to 30 N/cm. The restorations were placed on the abutments. No cement was used to ensure easy retrieval of restorations with no additional stress after cyclic loading [24]. Each assembly was then placed in a fabricated stainless-steel jig according to ISO14801 standard and was held perpendicular by a holder. To simulate the masticatory forces in the clinical setting, the assemblies were placed in a chewing simulator (Chewing Simulator CS-4, Mechatronik, Germany) for cyclic loading [14]. A total of 500,000 cycles (corresponding to 20 months of mastication) with 75 N load and 1 Hz frequency were applied to the triangular ridge of the mesiobuccal and mesiolingual cusps of the crowns perpendicular to the horizontal axis of each specimen [25]. After cyclic loading, the microgap was measured again at the respective points as explained earlier. The difference between the microgap values measured before and after cyclic loading was reported as the horizontal microgap [23] (Figure 3).

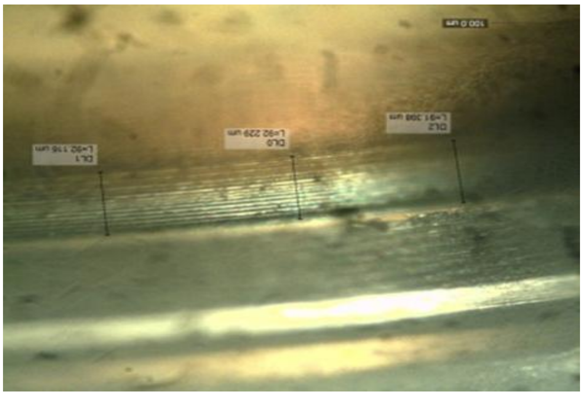

Figure 3. Horizontal microgap

Fuchsine dye (Merck, Germany) was used to assess the microleakage. For this purpose, the superior contact surface of the abutments was sealed with one layer of red dental wax and one coat of nail varnish to prevent leakage of fuchsine through this surface into the abutment [26]. The fuchsine solution was prepared according to the manufacturer's instructions, and the assemblies were immersed in it and incubated at 37°C for 24 hours [15,26]. Next, the abutment screw was opened by a hand wrench, and the abutments were separated from the fixtures. To assess the penetration depth of fuchsine at the implant-abutment interface, the fixtures were sectioned at the center using a Mecatome (T201A; Presi, France) [15]. The penetration depth of fuchsine in each specimen was measured under a stereomicroscope at x75 magnification at three points in each half-circle; the mean of the values measured at 6 points was calculated and reported as the microleakage of the respective specimen in micrometers (µm) [15] (Figure 4).

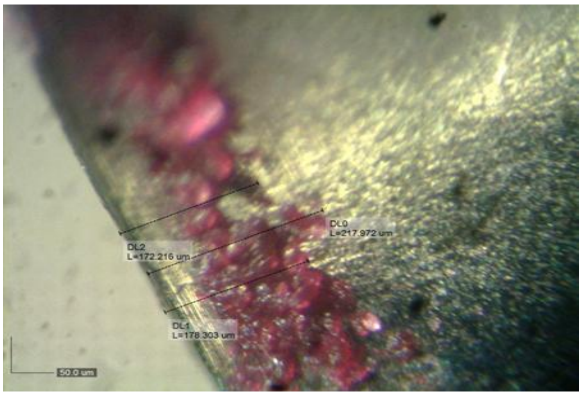

Figure 4. Assessment of microleakage by measuring the penetration depth of fuchsine

Data were analyzed using SPSS version 20 via t-test at 0.05 level of significance.

Results

Table 1 presents the amount of microgap in the two groups before and after cyclic loading. According to t-test, the change in microgap after cyclic loading compared with before was not significant in the control group (P=0.724). However, in the test group, the amount of microgap significantly increased after cyclic loading compared with before (P=0.000).

Table 2 presents the mean amount of microleakage in the two groups. According to t-test, microleakage in the test group was significantly greater than that in the control group (P=0.019).

Table 1. Amount of microgap (μm) in the two groups before and after cyclic loading

Group	Mean and std. deviation	Minimum	Maximum	P value
Control group, before cyclic loading	1.48±0.59	2.34	0.79	0.724
Control group, after cyclic loading	2.44±1.04	0.88	3.81	
Test group, before cyclic loading	2.35±0.95	0.98	3.14	0.000
Test group, after cyclic loading	4.38±0.98	2.68	5.33	

Table 2. Mean amount of microleakage (μm) in the two groups

Group	Mean and std. deviation	Minimum	Maximum	P value
Control (n=6)	32.35±12.5	18.32	51.55	0.019
Test (n=6)	60.99±21.8	34.01	92.30	

Discussion

This study assessed the effect of horizontal cantilever on microgap and microleakage at the implant-straight abutment interface in cement-retained crowns after cyclic loading. The results showed that the change in microgap after cyclic loading compared with before was not significant in the control group (P=0.724). However, in the test group, the amount of microgap significantly increased after cyclic loading compared with before (P=0.000). Microleakage in the test group was significantly greater than that in the control group (P=0.019). Thus, the null hypothesis of the study was rejected.

Several studies have reported greater bone loss at the cantilever site. For instance, Barbier et al. [27] reported an increase in the number of osteoclasts and presence of higher number of inflammatory lesions at the cantilever site compared with fixed prosthesis supported by dental implants at both sides. Also, they noticed an increase in trabecular bone density and increased thickness of cortical bone under cantilever prosthesis. Liu and Wang [28] reported that presence of cantilever generated higher levels of destructive forces and resulted in greater bone loss. Precision of contact refers to the optimal connection of implant and abutment at the interface [27]. A microgap forms at this site when the abutment is connected to the fixture. Although no consensus has been reached regarding the ideal precision of contact at this interface, it has been reported that complications can be prevented by minimizing the misfit [29,30]. Many attempts have been made to minimize microgap such as the use of wider implants, changing the abutment type, and changing the type of implant-abutment connection [31,32]. Although microgap at the interface of internal connection abutments has been extensively evaluated, studies regarding the implant-abutment fit in cantilever crowns after cyclic loading are limited [33].

Titanium implants were used in the present study since titanium is the most commonly used material for the fabrication of implant fixtures. The connection type was Morse-Taper, because this connection type has advantages such as better implant-abutment fit, reduction of bacterial microleakage and microgap, reduction of peri-implant bone loss, and reduction of screw loosening [34,35].

Previous studies using titanium abutments with internal connection have reported microgap values at the implant-abutment interface between 0 and 8.16 μm [7,36]. The mean microgap values obtained in the present study were < 10 μm, which are clinically acceptable. Variations in the reported microgap values in different studies can be due to different connection types, loading conditions, and methods of microgap measurement.

The first time that the abutment screw is tightened, the contact between the implant and screw threads only occurs through the micro-roughness of surfaces. A 2% to 10% reduction in preload in the first seconds and minutes of loading leads to formation of the settling effect [37]. Thus, the abutment screw was retorqued after 10 minutes with the same value as the primary torque in the present study [37]. Romeed et al. [35] reported larger microgaps in crowns with horizontal cantilever that received off-axial (angulated) loads compared with the control group, which was in agreement with the present findings. In contrast to the present study, Gehrke et al. [38] reported that cyclic loading increased the implant-abutment fit. This difference may be due to the variations in the number of load cycles, frequency of cycles, direction of load application, and some other factors [38].

One important consideration in placement of implant-supported restorations is to minimize the number of bacteria that colonize the trans-mucosal part of restorations [22]. Evidence shows that oral microbiota can colonize the implant-abutment interface and cause peri-implant inflammation. A number of factors may affect this occurrence such as precise connection of implant components, the applied torque, and masticatory forces applied to the implant [9]. In contrast to the present findings, Koutouzis et al. [39] showed that Morse-Taper implant systems had insignificant bacterial microleakage at the implant-abutment interface. Evidence shows that dynamic loads at the implant-abutment interface have a pumping effect and increase bacterial leakage [40]. Tripodi et al. [41] demonstrated that conical implant-abutment interface did not prevent microleakage at the molecular level or even in unloaded conditions.

In general, it has been shown that implants with Morse-Taper connection have higher resistance to bacterial microleakage than implants with external hexagon connection. However, some levels of microleakage at the molecular level always exist [8]. Da Silva-Neto et al. [42] showed that the microleakage increased in all connection types (internal connection, external connection, and Morse-Taper) by progressively increasing the load. Regarding conical connections, it is stated that compressive forces can cause further penetration of abutment into the implant body, which may eliminate or decrease the vertical microgap [43]. However, the clinical setting is different, and tensile forces may be applied to the implant-abutment connection and increase the microgap [42].

Fuchsine solution was used for assessment of microleakage in this study because its molecular size is similar to that of bacterial toxins. Also, the pattern of microleakage in bacterial leakage models and dye penetration test is reportedly the same [44].

The length of cantilever has a key role in stress distribution around dental implants. By an increase in cantilever length, greater stress is applied to the implants [45]. The tensile loads along the cantilever increase the vertical load by up to 40% [36]. To decrease the effect of cantilever, the occlusal table should be down-sized, occlusal contacts should be decreased, and occlusal interferences in lateral movements should be eliminated [45]. Also, whenever the treatment plan includes a cantilever crown, prefabricated abutments should be used for a precise fit between the abutment and fixture in order to minimize microgap and microleakage [21,44].

This study had some limitations. Microgap and microleakage were only evaluated in one implant-abutment system. Further studies are required to assess the microgap and microleakage in use of different implant-abutment systems under different cyclic loading conditions. Also, abutments with different types (straight versus angulated) and heights should be investigated in future studies.

Conclusion

The present results indicated that horizontal cantilever caused horizontal microgap and increased the microleakage at the implant-straight abutment interface.

References

1. Roccuzzo A, Jensen SS, Worsaae N, Gotfredsen K. Implant-supported 2-unit cantilevers compared with single crowns on adjacent implants: A comparative retrospective case series. J Prosthet Dent.2020 May 1;123(5):717-23.

2. Van Nimwegen WG, Raghoebar GM, Tymstra N, Vissink A, Meijer HJ. How to treat two adjacent missing teeth with dental implants. A systematic review on single implant-supported two-unit cantilever FDP's and results of a 5-year prospective comparative study in the aesthetic zone. J Oral Rehabil.2017 Jun;44(6):461-71.

3. Zurdo J, Romão C, Wennström JL. Survival and complication rates of implant-supported fixed partial dentures with cantilevers: a systematic review. Clin Oral Implants Res. 2009 Sep;20 Suppl 4:59-66.

4. Aglietta M, Siciliano VI, Zwahlen M, Brägger U, Pjetursson BE, Lang NP, Salvi GE. A systematic review of the survival and complication rates of implant supported fixed dental prostheses with cantilever extensions after an observation period of at least 5 years. Clin Oral Implants Res. 2009 May; 20(5):441-51.

5. Sahin C, Ayyildiz S. Correlation between microleakage and screw loosening at implant-abutment connection. J Adv Prosthodont. 2014 Feb 1;6(1):35-8.

6. Alsubaiy EF. Abutment screw loosening in implants: A literature review. J Family Med Prim Care. 2020 Nov 30; 9 (11):5490-5494.

7. Tsuge T, Hagiwara Y. Influence of lateral-oblique cyclic loading on abutment screw loosening of internal and external hexagon implants. Dent Mater J. 2009 Jul; 28(4): 373-81.

8. Mishra SK, Chowdhary R, Kumari S. Microleakage at the Different Implant Abutment Interface: A Systematic Review. J Clin Diagn Res. 2017 Jun;11(6):ZE10-ZE5.

9. Devaraju K, Rao SJ, Joseph JK, Kurapati SR. Comparison of biomechanical properties of different implant-abutment connections. Indian J Dent Sci. 2018;10(3):180-3.

10. Hotinski E, Dudley J. Abutment screw loosening in angulation-correcting implants: An in vitro study. J Prosthet Dent. 2019 Jan;121(1):151-5.

11. Donley TG, Gillette WB. Titanium endosseous implant-soft tissue interface: a literature review. J Periodontol. 1991 Feb;62(2):153-60.

12. Rismanchian M, Hatami M, Badrian H, Khalighinejad N, Goroohi H. Evaluation of microgap size and microbial leakage in the connection area of 4 abutments with Straumann (ITI) implant. J Oral Implantol. 2012 Dec;38(6):677-85.

13. Dincer Kose O, Karataslı B, Demircan S, Kose TE, Cene E, Aya SA, Erdem MA, Cankaya AB. In Vitro Evaluation of Manual Torque Values Applied to Implant-Abutment Complex by Different Clinicians and Abutment Screw Loosening. Biomed Res Int. 2017;2017:7376261.

14. Pardal-Peláez B, Montero J. Preload loss of abutment screws after dynamic fatigue in single implant-supported restorations. A systematic review. J Clin Exp Dent. 2017 Nov 1;9(11):e1355-e61.

15. Pimentel AC, Manzi MR, Sartori SG, da Graça Naclério-Homem M, Sendyk WR. In vivo effectiveness of silicone gel sheets as barriers at the inner microgap between a

prosthetic abutment and an external-hexagon implant platform. Int J Oral Maxillofac Implants. 2014 Jan-Feb; 29 (1):121-6.

16. Macedo JP, Pereira J, Vahey BR, Henriques B, Benfatti CAM, Magini RS, López-López J, Souza JCM. Morse taper dental implants and platform switching: The new paradigm in oral implantology. Eur J Dent. 2016 Jan-Mar;10(1):148-54.

17. Peruzetto WM, Martinez EF, Peruzzo DC, Joly JC, Napimoga MH. Microbiological Seal of Two Types of Tapered Implant Connections. Braz Dent J. 2016 May-Jun;27(3):273-7.

18. Tsuge T, Hagiwara Y, Matsumura H. Marginal fit and microgaps of implant-abutment interface with internal anti-rotation configuration. Dent Mater J. 2008 Jan;27(1):29-34.

19. Weng D, Nagata MJ, Bell M, Bosco AF, De Melo LG, Richter EJ. Influence of microgap location and configuration on the periimplant bone morphology in submerged implants. An experimental study in dogs. Clin. Oral Implants Res. 2008 Nov;19(11):1141-7.

20. Zanardi PR, Costa B, Stegun RC, Sesma N, Mori M, Laganá DC. Connecting accuracy of interchanged prosthetic abutments to different dental implants using scanning electron microscopy. Braz Dent J. 2012;23(5):502-7.

21. Altherban W. An in vitro analysis of cantilever effect on the reverse torque measurement for a screw retained single molar crown. Tufts University School of Dental Medicine. 2019:29(4):791-7.

22. Gupta S, Gupta H, Tandan A. Technical complications of implant-causes and management: A comprehensive review. Natl J Maxillofac Surg. 2015 Jan-Jun;6(1):3-8.

23. Siadat H, Pirmoazen S, Beyabanaki E, Alikhasi M. Does Abutment Collar Length Affect Abutment Screw Loosening After Cyclic Loading? J Oral Implantol. 2015 Jul;41 Spec No: 346-51.

24. Barbier L, Schepers E. Adaptive bone remodeling around oral implants under axial and nonaxial loading conditions in the dog mandible. Int J Oral Maxillofac Implants. 1997 Mar-Apr;12(2):215-23.

25. Larrucea Verdugo C, Jaramillo Núñez G, Acevedo Avila A, Larrucea San Martín C. Microleakage of the prosthetic abutment/implant interface with internal and external connection: in vitro study. Clin Oral Implants Res. 2014 Sep; 25(9):1078-83.

26. Ebadian B, Hatami M. Tooth-supported cantilevered FDPs: a review. J Isfahan Dent Sci 2010;6(4):410-25.

27. Berberi A, Tehini G, Rifai K, Bou Nasser Eddine F, El Zein N, Badran B, Akl H. In vitro evaluation of leakage at implant-abutment connection of three implant systems having the same prosthetic interface using rhodamine B. Int J Dent. 2014;2014:351263.

28. Liu Y, Wang J. Influences of microgap and micromotion of implant-abutment interface on marginal bone loss around implant neck. Arch Oral Biol. 2017 Nov;83:153-60.

29. Moilanen P, Hjerppe J, Lassila LV, Närhi TO. Fracture strength and precision of fit of implant-retained monolithic zirconia crowns. J. Oral Implantol. 2018 Oct;44(5):330-4.

30. Nascimento Cd, Ikeda LN, Pita MS, Pedroso e Silva RC, Pedrazzi V, Albuquerque RF, Ribeiro RF. Marginal fit and microbial leakage along the implant-abutment interface of fixed partial prostheses: An in vitro analysis using Checkerboard DNA-DNA hybridization. J Prosthet Dent. 2015 Dec;114(6):831-8.

31. Prithviraj D, Muley N, Gupta V. The Evolution of External and Internal Implant–Abutment Connections: A Review. Int Dent Res. 2012 Apr.15;2(2):37-42.

32. Jorge JR, Barao VA, Delben JA, Assuncao WG. The role of implant/abutment system on torque maintenance of retention screws and vertical misfit of implant-supported crowns before and after mechanical cycling. Int J Oral Maxillofac Implants. 2013 Mar-Apr;28(2):415-22.

33. Yeo IS, Lee JH, Kang TJ, Kim SK, Heo SJ, Koak JY, Park JM, Lee SY. The effect of abutment screw length on screw loosening in dental implants with external abutment connections after thermocycling. Int J Oral Maxillofac Implants. 2014 Jan-Feb;29(1):59-62.

34. Arnetzl GV, Payer M, Falkensammer F, Arnetzl G. Effect of double conical abutment screw on implant preload. Clin Oral Implants Res. 2016 May;27(5):553-7.

35. Romeed SA, Fok SL, Wilson NH. Finite element analysis of fixed partial denture replacement. J Oral Rehabil. 2004 Dec;31(12):1208-17.

36. Jesus Tavarez RR, Bonachela WC, Xible AA. Effect of cyclic load on vertical misfit of prefabricated and cast implant single abutment. J Appl Oral Sci. 2011 Jan-Feb;19(1):16-21.

37. Assunção WG, Dos Santos PH, Delben JA, Gomes ÉA, Barao VA, Tabata LF. Effect of misfit on preload maintenance of retention screws of implant-supported prostheses. JMEPEG. 2009 Oct;18(7):935-8.

38. Gehrke SA, Delgado-Ruiz RA, Prados Frutos JC, Prados-Privado M, Dedavid BA, Granero Marín JM, Calvo Guirado JL. Misfit of Three Different Implant-Abutment Connections Before and After Cyclic Load Application: An In Vitro Study. Int J Oral Maxillofac Implants. 2017 Jul/Aug; 32 (4):822-9.

39. Koutouzis T, Mesia R, Calderon N, Wong F, Wallet S. The effect of dynamic loading on bacterial colonization of the dental implant fixture-abutment interface: an in vitro study. J Oral Implantol. 2014 Aug;40(4):432-7.

40. Harder S, Dimaczek B, Açil Y, Terheyden H, Freitag-Wolf S, Kern M. Molecular leakage at implant-abutment connection--in vitro investigation of tightness of internal conical implant-abutment connections against endotoxin penetration. Clin Oral Investig. 2010 Aug;14(4):427-32.

41. Tripodi D, D'Ercole S, Iaculli F, Piattelli A, Perrotti V, Iezzi G. Degree of bacterial microleakage at the implant-abutment junction in Cone Morse tapered implants under loaded and unloaded conditions. J Appl Biomater Funct Mater. 2015 Dec 18;13(4):e367-71.

42. da Silva-Neto JP, Prudente MS, Dantas TS, Senna PM, Ribeiro RF, das Neves FD. Microleakage at Different Implant-Abutment Connections Under Unloaded and Loaded Conditions. Implant Dent. 2017 Jun;26(3):388-92.

43. Moris IC, Faria AC, de Mattos Mda G, Ribeiro RF, Rodrigues RC. Mechanical analysis of conventional and small diameter conical implant abutments. J Adv Prosthodont. 2012 Aug;4(3):158-61.

44. Tsuruta K, Ayukawa Y, Matsuzaki T, Kihara M, Koyano K. The influence of implant-abutment connection on the screw loosening and microleakage. Int J Implant Dent. 2018 Apr 9;4(1):11.