Bio-Medical Materials and Engineering 1 (2020) 1–10
DOI 10.3233/BME-206008
IOS Press

Dynamic and static load performance of dental biomaterial systems with conical implant-abutment connections

Mehmet Can Basgil[a], Cem Kurtoglu[b], Koray Soygun[b,*], Yunus Uslan[c] and Teyfik Demir[c]
[a] *Istanbul Okmeydani Dental Health Hospital, Department of Prosthodontics, Istanbul, Turkey*
[b] *Department of Prosthodontics, Faculty of Dentistry, Cukurova University, Adana, Turkey*
[c] *Mechanical Engineering, TOBB University of Economics and Technology, Ankara, Turkey*

Received 13 March 2020
Accepted 3 October 2020

Abstract.
BACKGROUND: The stability of the implant-abutment interface is an important factor that influences load distribution on the marginal bone.
OBJECTIVE: In this study, three dental implants with the same connection were subjected to different dynamic loading cycles. The fracture strengths and the horizontal compatibility of implants were assessed.
METHODS: Eighty four implant specimens were embedded in a polyacetal cylinder as simulated bone loss of 3 mm from the implant platform. Three of the implants were used to determine the endurance limit. The other specimens were subdivided into four subgroups ($n = 6$): three for dynamic + static loading, and one for static loading (control group). The tests were performed by applying a compression load. The dynamic loading experiments included three different cycles with endurance upper limit loads at a frequency of 10 Hz.
RESULTS: The differences between the fracture strength values of the implant brands were found to be statistically significant. However, there were no meaningful differences between the fracture strength values of implants of the same brand. The specimens of the DTI implant system had the lowest strength (647.9 ± 41.5 N) and the SEM analysis indicated that the Implantium implant system had the shortest horizontal gaps.
CONCLUSIONS: There was a negative correlation between the fracture strengths and size of the microgaps. The importance of these in vitro results needs to be validated by clinical trials because the loads in the mouth can be applied from various angles.

Keywords: Dental implant, dynamic loading, horizontal gap, internal conical connection

1. Introduction

Dental implants have been used extensively in treating single, partial or total edentulism with satisfactory survival rates. However, adverse biological responses and prosthetic restoration complications

*Corresponding author: Koray Soygun, Department of Prosthodontics, Faculty of Dentistry, Cukurova University, 01380 Adana, Turkey. Tel.: +905056443928; E-mail: koraysoygun@hotmail.com.

can occur. The stability of the implant-abutment interface is an important factor that influences load distribution on the marginal bone. Some biological and prosthetic complications can occur due to the misfits of the implant-abutment interface, such as: (i) biological complications arising from the increased load transfer to the bone, bone loss, or from the development of micro flora in the microgap between the implant and abutment [1–3]; and (ii) prosthetic complications caused by screw loosening or fracture and implant loss [4].

The implant–abutment connection is the weakest point of dental implant fixtures because it must resist maximal and permanent masticatory forces. In terms of the mechanical properties of implant connections, it has been assumed that some abutment connections might provide better resistance to displacement, caused by excessive occlusal forces [5]. In this regard it has been speculated that this displacement would increase stress/strain on the endosseous implant and promote the acceleration of marginal bone loss [6,7].

There are several connection designs between the implant and the abutment. One of them is the internal conical connection, introduced to provide an intimate implant-abutment contact by improving the mechanical stability of the abutment to avoid abutment loosening and to decrease perimplant bone loss [8]. The fixation and stability of these systems are not screw functions but are granted by the frictional resistance results from the contact between the conical mating parts of the abutment and the implant. The stability of this system seems to provide a high resistance to bending forces at the implant-abutment interface [9,10].

The aim of this study was to compare the fracture strengths of implants with internal conical connection after different dynamic loading cycles. The uniformity of the fracture strength of the implants formed the null hypothesis of the study.

2. Materials and methods

The fixture-abutment connection types of each implant brand used in the study, i.e. Implantium (Dentium, Seul, South Korea), Mode Implant (Mode Medical Istanbul, Turkey) and DTI implants (DTI Implant System Istanbul, Turkey), had a 11 degree internal conical connection type (Table 1). The fixture-abutment internal connection length of DTI brand implants is 3 mm. 0.81 mm of this length is the internal hex connection length. The internal conical connection length of this implant is 2.19 mm. The fixture-abutment internal connection length of the Implantium brand implants is 3 mm. 1.14 mm of this length is internal hex connection. The fixture-abutment internal connection length of Mode brand implants is 3 mm. 1.5 mm of this length has an internal octagon structure. The other 1.5 mm part is the length of the internal conical connection.

Twenty-eight implants, abutments and their corresponding screws were delivered from commercially available stocks for each brand. Implants were centrally embedded in a polyacetal cylinder with an inner diameter of 20 mm and a height of 30 mm. The implants were centred in the cylinder as simulated bone loss of 3 mm from the implant platform. All abutments were placed on the corresponding embedded implants, and the screws were tightened according to the manufacturers' recommendations (25 N, 30 N, 30 N for Mode, Implantium and DTI respectively). One implant for each brand was set apart for SEM analysis. A hemispherical loading device made of cobalt-chromium alloy was manufactured and seated onto the unmodified abutments. The distance from the centre of the hemisphere to the top face of polyacetal cylinder was standardized at 11 mm.

Three implants were used to determine the endurance limit for each brand. All the specimens were then subdivided into four subgroups ($n = 6$), three subgroups for dynamic + static loading as test groups

Table 1
Properties and compositions of implant components used in this study

	DTI	Implantium	Mode
Fixture diameter/length (mm) - Grade number	4.5/11.5 - Grade 5	4.5/12 - Grade 4	4.7/11.5 - Grade 4
Abutment diameter/cuff height (mm) - Grade number	5/1 - Grade 5	4.5/1 - Grade 5	4.5/1 - Grade 5
Screw abutment	Grade 5	Grade 5	Grade 5
internal connection type, conical angle (°)	Conical connection with internal hex, 11	Conical connection with internal hex, 11	Conical connection with internal octagonal, 11
Manufacturer	DTI Implant Systems, Istanbul, Turkey	Dentium, Seul, South Korea	Mode Medical, Istanbul, Turkey
Lot number	TR01010402	A22D03116	0114-004

*Composition of Grade 4: Titanium 99%, Oxygen 0.4%, Iron 0.3%, Nitrogen 0,05%, Hydrogen 0.15%, Carbon 0.1%. **Composition of Grade 5 (Ti6Al4V): Nitrogen 0.05%, Carbon 0.08%, Hidrogen 0.012%, Iron 0.25%, Oxygen 0.2%, Aluminum 5.5–6.50%, Vanadium 3.5–4.5%, Titanium balance%.

(250,000 cycles group (DSL1), 1,000,000 cycles group (DSL2), 2,500,000 cycles group (DSL3)), and one subgroup for static loading (SL) as control group. The specimens were then placed and clamped in a stainless steel polyacetal jig at a 30° angle between the implant axis and the direction of loading.

The tests, according to ISO 14801, were performed by applying a compression load 30 ± 2 degrees off the axis of the implant (Fig. 1). This resulted in a combination of compression, bending, and shear loads in the device [11]. First static loadings were performed with control groups using Instron 5944 (Instron Corporation, Massachusetts, USA) with a 5mm/min crosshead speed until failure occurred. Maximum loads and yield strengths were recorded.

During dynamic loading, endurance tests were performed with three specimens from each of the implant brands. Under static loading strength values were also recorded. In the endurance limit test, the number of dynamic cycles were defined as 1,000,000 cycles of 10 Hz frequency with 2 N preload. The test series were initiated for each group with load values corresponding to half of the yield stress values obtained as a result of the relevant static tests. The endurance limit values, the highest load value that the specimens were able to complete robustly, were determined and used as the load values during dynamic loading experiments.

Dynamic loadings were performed at three different cycles; 250,000, 1,000,000, 2,500,000 to simulate three month-, one year-, and two and a half years of use, with 2N preload, 200 N for DTI, 250 N for Mode, 350 N for Implantium as the upper load limit by the endurance limit test results at frequency of 10 Hz for three different test groups. After dynamic loading, static loading was performed. Specimens were loaded until failure and all the data were recorded. Kruskal Wallis test ($p > 0.017$) and Wilcoxon test ($p > 0.017$) was performed for statistical analysis.

In order to compare the horizontal compatibility of implant-abutment connection types, each abutment was placed on the corresponding implants and the screws were tightened according to the manufacturer's recommendation. Each specimen was embedded in polyacetal and mid-sectioned along longitudinal axis. The internal configuration was visually inspected using SEM (JSM 6400, Jeol, Japan).

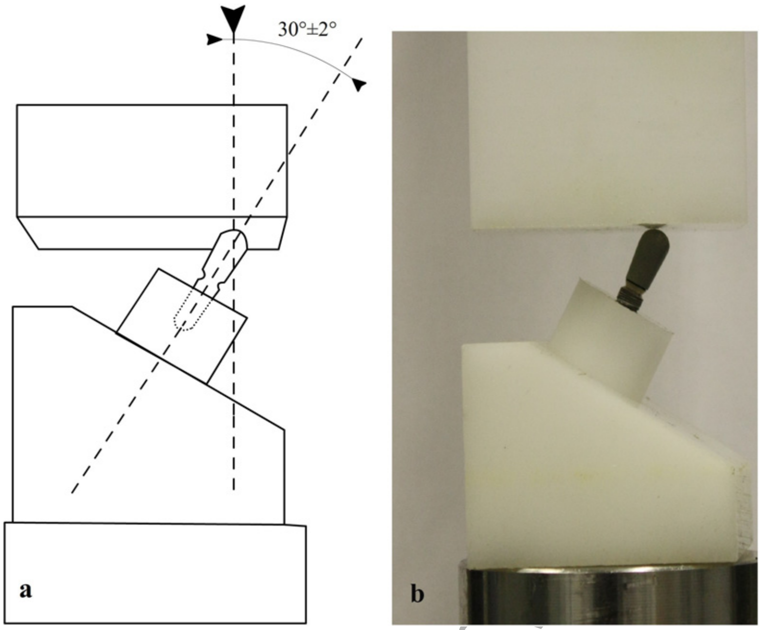

Fig. 1. Dynamic loading test setup for the dental implants. (a) Schematic view and (b) view obtained from the test.

Table 2
Values of endurance limit in the implant samples

Sample	DTI			Implantium			Mode		
	Load (N)	Cycle		Load (N)	Cycle		Load (N)	Cycle	
1	250	106,565	F	350	1,000,000	R	250	1,000,000	R
2	200	1,000,000	R	400	671,430	F	300	663,355	F
3	200	1,000,000	R	350	1,000,000	R	250	1,000,000	R

F: Failure, R: Robust.

3. Results

The mechanical tests were performed under static or dynamic loadings. The load-bearing capacities of the implant were obtained using the static loading procedure. Lifetime of the implants was evaluated by using the dynamic loading procedure. The loads to be applied to the DTI, Implantium and Mode brand implants was determined to be 200 N, 350 N, 250 N respectively (Table 2) by the dynamic loading experiments.

The mean fracture strength values of static and dynamic loading of all trademark implants used in the study were presented (Table 3). The nonparametric Kruskal Wallis test was used to observe whether there was a significant difference between the data for Implantium, DTI and Mode brand implants. There was a statistically significant difference between the groups. The Mann–Whitney U test was used for binary comparisons of different brands of implant groups in the same dynamic loading cycle ($p < 0.017$). Fracture strength values differed significantly among the groups. The specimens of DTI implant system revealed the lowest strength (647.9 ± 41.5 N; Fig. 2A).

Table 3
The maximum load values after the applied cycles of the implants used in the study

	DTI Mean ± SD	Implantium Mean ± SD	Mode Mean ± SD
SL	647.9 ± 41.5[a,b]	802.8 ± 93.3[a]	862.5 ± 22.1[b]
DSL 1	681.4 ± 7.9[c]	707.6 ± 30.2[d]	816.1 ± 35.0[c,d]
DSL2	675.3 ± 21.7[e]	697.3 ± 15.9[f]	791.7 ± 19.4[e,f]
DSL 3	699.2 ± 6.7[g]	700.5 ± 25.2[h]	815.4 ± 24.3[g,h]

Note: The same superscript indicates significant differences.

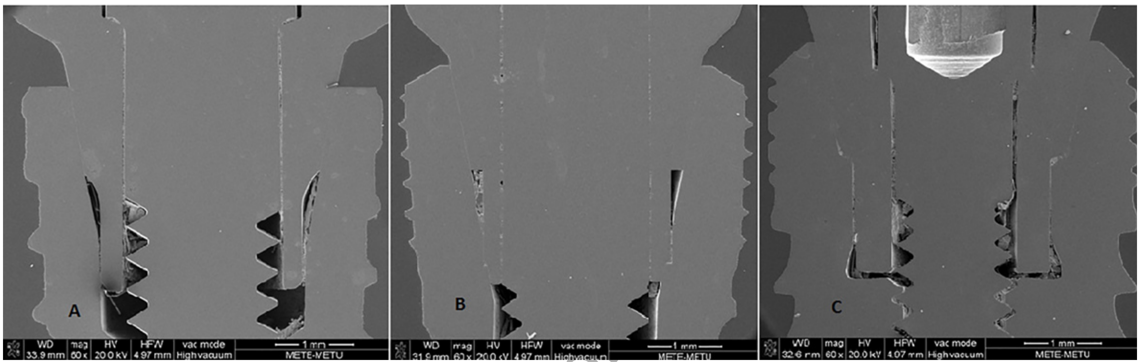

Fig. 2. Scanning electron microscopy images (original magnifications ×60) of (A) DTI, (B) Implantium and (C) Mode brand implants.

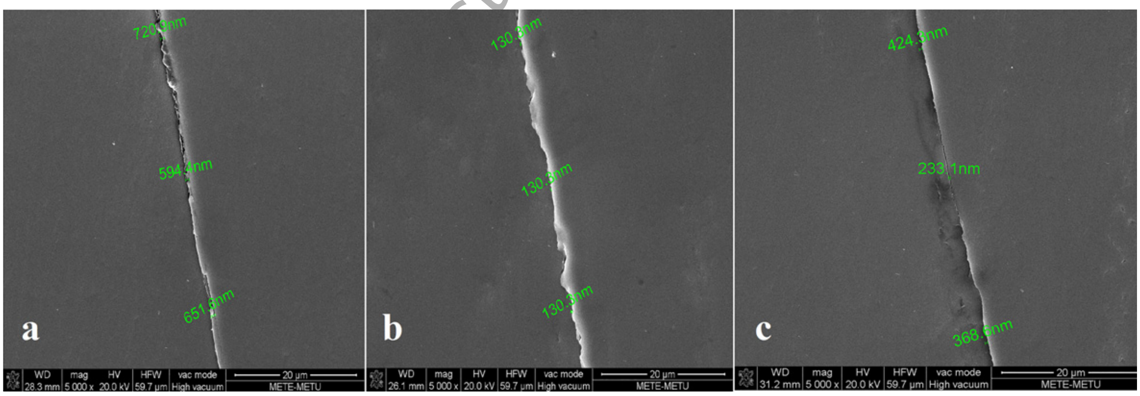

Fig. 3. Horizontal gap of implant-abutment connection. (a) DTI, (b) Implantium and (c) Mode SEM (original magnifications ×5000).

The Wilcoxon test was used to compare the results of different dynamic loading cycles within the groups. The test results were analysed by the Bonferroni regression and differences were not found to be statistically significant ($p < 0.017$). Horizontal gaps were visualized and measured by SEM (Figs 2, 3 and Table 4).

Table 4
Horizontal gap values of the implants (nm)

	DTI	Implantium	Mode
Med (Min–max)	472.1 (116.6–936.2)	233.1 (116.6–469.9)	291.4 (116.6–608.5)

4. Discussion

Dentium, DTI and Mode Implant brand implants and abutments with internal conical connection were used in the present study. In order to perform dynamic and static loading tests, implants were placed in polyacetal cylinders simulating 3 mm bone loss in accordance with ISO 14801. The specimens were then subjected to dynamic loading at 250,000, 1,000,000 and 2,500,000 cycles and then subjected to static loading to determine the maximum fracture strength. Horizontal spacing measurements were also made to compare the connectivity between the implant and the abutment.

Nishioka et al. [12] reported that internal conical connected systems had a better mechanical engagement and stability than those of the external connected systems. Coppedê et al. [10] compared the implant systems with the internal conical connect to those with the internal hexagon-connected implant systems and observed screw fractures in the hexagonal connected systems, but not screw fracture in the conical connect systems, which are more resistant to oblique forces than systems with internal hexagonal connections. In implants with internal hexagon connections, it has been stated that the oblique forces were met by the screw, and therefore the yield strength of the joint was actually the yield strength of the screw. However, in the systems with conical connection, the inclined forces coming from the implant can be compensated by the inclined inner surface. Therefore less stress would be transmitted to the screw and the bone around the implant [9,10]. In the internal conical implant systems, the microgap between the implant and the abutment was less than in other systems [13]. In this study, implants with internal conical implant-abutment connection were preferred.

In this study, the specimens were placed in high density polyacetal cylinders with elastic modulus of about 3.1 GPa for ease of application, availability and reproducibility. The use of acrylic with the elastic modulus close to the bone is quite common [14–16]. Implanted with a polyacetal cylinder does not fully demonstrate the mechanical conditions exhibited by an osseointegrated implant. However, this material has been preferred in in vitro conditions. Furthermore, to simulate bone loss of 3 mm, the neck region of the implants was incised by 3 mm [17].

Dynamic- and static-loading tests were simulated in the laboratory environment. In such studies, different angles such as 30° and 45° have been used [10,18]. It has been reported that the reason for loading with a 45° angle was to imitate the occlusion. However, it should be borne in mind that most patients have a few millimeters of overjet or overbite. It has been stated that the application of 30° angle imitated the root incline in the upper front teeth and the incisal relation in class I in the mouth. Application with a 30° angle causes the load to be distributed both horizontally and vertically [17]. This ensures the better simulation of the environment in mouth where the implant is subjected to a combination of forces, such as compression, bending, and shear [11].

Maximum loads applied to each implant brand during dynamic loading were measured by performing a durability limit test. The result of this test was 200 N for DTI brand implants, 350 N for Implantium brand implants, and 250 N for Mode brand implants. This experiment allowed us to preserve the integrity of the implant specimens with lower endurance limits. The chewing forces coming from the teeth in the mouth vary from about 20 N to 120 N [14]. The test results showed statistically significant differences between the implant brands.

The specimens were subjected to 250,000, 1,000,000 and 2,500,000 cycles of dynamic loading corresponding to clinically critical three months, one year, and two and a half years. In another study comparing six different implant connection systems, 800,000 dynamic loads were applied and then static loading was performed, and 800,000 dynamic loads were assumed to be one year [14]. In this study, 1,000,000 dynamic loads were considered to be equivalent of one year. In another study by Marchetti et al. [17], 5,000,000 cycles were considered to be six years. Thus, the amount of in vitro loading does not seem to be defined precisely.

In vitro dynamic loading experiments are generally considered to be one of the most important methods in evaluating the long term behaviour and fracture strength of implants [14]. Dynamic loading was performed to test the difference in fatigue strength of implants exposed to chewing loads in the mouth. DTI, Implantium and Mode implants were subjected to dynamic loading of 250,000, 1,000,000 and 2,500,000 cycles. Static forces were then applied until the specimens were broken. A single static loading was applied to the control groups before the dynamic loading. The maximum load values of the specimen groups were compared. The reason why the yield strength values were not used in comparisons was that the permanent deformation seen in the yield strength value could not be controlled in the mouth and the implant could continue to function in the mouth. In order to better reflect the clinical events, the tests were made until samples were broken and the maximum load values were compared.

There was no statistically significant difference between the test groups of the same brand implants and the control group. This may be due to the fact that the internal conical connection system could tolerate the loads better on the implant.

Dittmer et al. [14] compared six different implant brands with different implant-abutment connection types of dynamic loading and non-dynamic loading. Three of the implants used had internal conical abutment connection and others had internal hexagon abutment connection. Only static loading values of implants with internal hexagonal abutment connection were compared to those of dynamic loading followed by static loading. The decline in values due to dynamic loading was expressed as a percentage (about 50%). In implants with an internal conical implant-abutment connection, the results of the dynamic loading group were compared only to those of the static loading group, and the decrease in the dynamic loading of the values was reported as a percentage (about 12%). The dynamic preload and dynamic post-load fracture strength values of implants with internal conical connections did not show any significant difference when compared statistically, which was similar to the results of our current study. It has been stated that the cause of the decrease in the results could have been due to the loosening of the screw that connects the abutment and the implant, the bending of the screw, the screw breaking, the breakage of the implant neck region, or the wear of the implant-abutment connection surface. It was evidenced that implants with different implant-abutment connection types and implants with internal conical connection showed the best results.

In a meta-analysis, the fracture strength values of 1,000,000 cycles and over-loaded implants were decreased compared to the fracture strength values of implants by 1,000,000 cycles of dynamic loading [19]. In our study, there was no statistically significant difference between dynamic loading groups and non-dynamic loading groups of the same brand of implants. Further work is needed to assess the long-term clinical success of implants. Many studies in the literature investigated implant-abutment connection types. However, most of these studies compared different types of connections and some concerned stress accelerated life-testing studies [20,21].

Chu et al. examined the effect of the internal conical abutment connection on the bone around the implant. They emphasized that small-diameter abutment and deep abutment connection transmits minimal stress to the bone around the implant. They also stated that, as the implant angle decreased, the implant wall thickness increased, so there was less stress in the vertical forces but no significant difference in horizontal forces. Furthermore, it has been reported that the stress in the bones around the implant was the result of the most abutment diameter, then the depth of the joint, and at least the angle of the joint [22].

The angles of implant-abutment connections used in our study were set as 11° for all brands. As a result, there was no expectation of a difference that may arise depending on the connection angle. When the design differences between the implant and the abutment were examined, the highest depth of contact between the implant and the abutment was found in Mode Implant specimens. Furthermore, when considering the implant wall thicknesses, the largest wall thickness was again found in the Mode implant. In addition, when the contact surfaces of the anti-rotational hex area located under the conical section of the implant-abutment connection were examined, the highest contact surface was again found for the Mode Implant. These data may be taken as the evidence as to why the Mode implant specimens had the highest fracture toughness values. However, it should also be noted that the implant diameter of the Mode implant was 0.2 mm larger than other brands.

One of the factors that affect implant success is the formation of the microgaps between implant-abutment connections. Microbial growth in these void areas are the main cause of peri-implant mucositis or peri-implantitis, leading to implant loss [23]. Implants with internal conical connectors have been reported to have a lower microleakage than implants with external connectors [24]. It has also been reported that the microgaps may be related to the insertion torque of the abutment screw [24].

When the implant and abutment are combined with the screw, moving as a whole is an important factor in the success of the system. An excessive microgap will disturb the integrity of the system and lower the fracture strength. For this reason, the microgap values between the implant and abutment in unloaded implant groups were compared (Fig. 3, Table 4). Horizontal gap values of DTI brand implants in our study were higher than other brands. This could be one of the reasons why DTI brand implants generally have lower fracture resistance than other brands. Microgap measurement can be done with different devices such as 3D microtomography, scanning electron microscope [25]. In our work, scanning electron microscopy was used for microgap measurement.

In our work only the use of the unloaded abutments in the dynamic microgap measurements could be seen as a limitation. A low number of specimens (i.e. less than ten) was used because of the limited budget of the study, which is why the data obtained were subjected to Bonferroni correction. This can be accomplished by including dynamically loaded specimens in the measurements.

5. Conclusions

Within the limits of the present study, we conclude the following:

(1) There was no difference in fracture strength values after dynamic loading of implants with internal conical implant-abutment connection under experimental conditions. However, there is a need for clinical studies because the loads in the mouth may come from different directions and the results of the study may be affected by these conditions.
(2) Since the materials used in the production of implants with an internal conical connection of 11° may differ, there may be differences in yield strength values. Therefore, it would not be right to compare

the brands with each other. However, it should not be forgotten that all implants will be successful in the mouth because the loads applied during the dynamic loading to all brands used in our study are higher than the loads coming to the implants in the mouth.

(3) The anti-rotational hex length and thickness in the abutment connection can affect the fracture strength values.

Conflict of interest

No potential conflict of interest was reported by the authors.

Funding

This study was partially supported by the Cukurova University Scientific Research Project in Adana under grant number TDK-2015-43834.

References

[1] K.X. Michalakis, H. Hirayama and P.D. Garefis, Cement-retained versus screw-retained implant restorations: A critical review, *Int J Oral Max Impl* **18**(5) (2003), 528.

[2] V.K. Jansen, G. Conrads and E.J. Richter, Microbial leakage and marginal fit of the implant-abutment interface, *Int J Oral Max Impl* **12**(4) (1997), 540.

[3] M. Quirynen, M. De Soete and D. Van Steenberghe, Infectious risks for oral implants: A review of the literature, *Clin Oral Implan Res* **13**(1) (2002), 19.

[4] R.L. Burguete, R.B. Johns, T. King and E.A. Patterson, Tightening characteristics for screwed joints in osseointegrated dental implants, *J Prosthet Dent* **71**(6) (1994), 599.

[5] T. Kitagawa, Y. Tanimoto, M. Odaki, K. Nemoto and M. Aida, Influence of implant/abutment joint designs on abutment screw loosening in a dental implant system, *J Biomed Mater Res B Appl Biomater* **75**(2) (2005), 463.

[6] S.E.T. Quaresma, P.R. Cury, W.R. Sendyk and C.A. Sendyk, A finite element analysis of two different dental implants: Stress distribution in the prosthesis, abutment, implant, and supporting bone, *J Oral Implantol* **34**(1) (2008), 6.

[7] C.L. Lin, S.H. Chang, W.J. Chang and Y.C. Kuo, Factorial analysis of variables influencing mechanical characteristics of a single tooth implant placed in the maxilla using finite element analysis and the statistics-based Taguchi method, *Eur J Oral Sci* **115**(5) (2007), 416.

[8] D. Bozkaya and S. Müftü, Mechanics of the taper integrated screwed-in (TIS) abutments used in dental implants, *J Biomech* **38**(1) (2005), 97.

[9] M.R. Norton, An in vitro evaluation of the strength of a 1-piece and 2-piece conical abutment joint in implant design, *Clin Oral Implants Res* **11**(5) (2000), 464.

[10] A.R. Coppedê, E. Bersani, G. de Mattos Mda, I.A. Sartori and R.F. Ribeiro, Fracture resistance of the implant-abutment connection in implants with internal hex and internal conical connections under oblique compressive loading: An in vitro study, *Int J Prosthodont* **22**(3) (2009), 286.

[11] P. Gehrke, G. Dhom, J. Brunner, D. Wolf, M. Degidi and A. Piattelli, Zirconium implant abutments: Fracture strength and influence of cyclic loading on retaining-screw loosening, *Quintessence Int* **37**(1) (2006), 26.

[12] R.S. Nishioka, L.G.O. de Vasconcellos and G.N. de Melo Nishioka, Comparative strain gauge analysis of external and internal hexagon, Morse taper, and influence of straight and ofset implant configuration, *Implant Dent* **20**(2) (2011), 32.

[13] Y. Maeda, T. Satoh and M. Sogo, In vitro differences of stress concentrations for internal and external hex implant-abutment connections: A short communication, *J Oral Rehabil* **33**(1) (2006), 78.

[14] M.P. Dittmer, S. Dittmer, L. Borchers, P. Kohorst and M. Stiesch, Influence of the interface design on the yield force of the implant–abutment complex before and after cyclic mechanical loading, *J Prosthodont Res* **56**(1) (2012), 24.

[15] T.C. Truninger, B. Stawarczyk, C.R. Leutert, T.R. Sailer, C.H. Hämmerle and I. Sailer, Bending moments of zirconia and titanium abutments with internal and external implant-abutment connections after aging and chewing simulation, *Clin Oral Implants Res* **23**(1) (2012), 18.
[16] A. Sundh and G. Sjögren, A study of the bending resistance of implant-supported reinforced alumina and machined zirconia abutments and copies, *Dent Mate* **24**(5) (2008), 617.
[17] E. Marchetti, S. Ratta, S. Mummolo, S. Tecco, R. Pecci, R. Bedini and G. Marzo, Evaluation of an endosseous oral implant system according to UNI EN ISO 14801 fatigue test protocol, *Implant Dent* **23**(6) (2014), 671.
[18] J.E. Pedroza, Y. Torrealba, A. Elias and W. Psoter, Comparison of the compressive strength of 3 different implant design systems, *J Oral Implantol* **33**(1) (2007), 7.
[19] R. Coray, M. Zeltner and M. Özcan, Fracture strength of implant abutments after fatigue testing: A systematic review and a meta-analysis, *J Mech Behav Biomed Mater* **62** (2016), 346.
[20] A.C. Freitas-Júnior, E.O. Almeida, E.A. Bonfante, N.R.F.A. Silva and P.G. Coelho, Reliability and failure modes of internal conical dental implant connections, *Clin Oral Implants Res* **24**(2) (2013), 202.
[21] J.A. Delben, V.A. Barão, M.B. Ferreira, N.R. da Silva, V.P. Thompson and W.G. Assunção, Influence of abutment-to-fixture design on reliability and failure mode of all-ceramic crown systems, *Dent Mater* **30**(4) (2014), 416.
[22] C.M. Chu, H.L. Huang, J.T. Hsu and L.J. Fuh, Influences of internal tapered abutment designs on bone stresses around a dental implant: Three-dimensional finite element method with statistical evaluation, *J Periodontol* **83**(1) (2012), 118.
[23] D.P. Callan, A. O'Mahony and C.M. Cobb, Loss of crestal bone around dental implants: A retrospective study, *Implant Dent* **7**(4) (1998), 266.
[24] C. Larrucea Verdugo, G. Jaramillo Núñez, A. Acevedo Avila and C. Larrucea San Martín, Microleakage of the prosthetic abutment/implant interface with internal and external connection: In vitro study, *Clin Oral Implants Res* **25**(9) (2014), 1083.
[25] A. Scarano, C. Mortellaro, L. Mavriqi, R. Pecci and L. Valbonetti, Evaluation of microgap with three-dimensional x-ray microtomography: Internal hexagon versus cone morse, *J Craniofac Surg* **27**(3) (2016), 685.