10.5005/jp-journals-10024-1952

ORIGINAL RESEARCH

Micromovement Evaluation of Original and Compatible Abutments at the Implant–abutment Interface

[1]Antoine Berberi, [2]Dagher Maroun, [3]Wasfi Kanj, [4]El Zoughbi Amine, [5]Aramouni Philippe

ABSTRACT

Introduction: Use of compatible abutments may increase micromovements between the abutments, and the inner part of the implant may increase the stress on marginal bone level. Also micromovement will change the volume of the inner space of the implant–abutment complex. The resulting pumping effect can transport even initially immobile microorganisms from the exterior to the interior and *vice versa*.

Objectives: The purpose of the study was to evaluate the mechanical comportment of OsseoSpeed™ Tx implants connected with original and compatible abutments *in vitro* under simulated clinical loading conditions.

Materials and methods: A total of 15 OsseoSpeed™ TX implants (4 × 11 mm) were used and divided into three groups (n = 5). Three types of abutments were used in the study; group I: Five original Ti Design™ abutments, group II: Five Natea™ abutments, and group III: Implanet™ abutments. Abutments used in groups II and III were all compatible with Astra Tech Implant System™. Implants were embedded into resin. Simulating the human masticatory cycle, the axial force vector was increased up to a defined maximum (25, 50, 75, 100, 125, 150, 175, and 200 N) and inclined 30° to the implant axis. A radiograph amplifier was used to convert the X-ray projection into a picture. The visual evaluation of the frames and the provided X-ray videos were evaluated for an existing microgap in width and length between the implant and the abutment.

Results: An initial width gap was observed in groups II and III in four of the five samples with an average of 6.5 and 5 µm respectively. When the axial forces reach 75 N, only groups II and III demonstrated a gap width of 5.2 ± 3.63 and 4.8 ± 3.03 µm, and a gap length of 5.2 ± 3.63 and 94 ± 125.3 µm respectively. At 200 N, group I showed a gap width of 8.4 ± 1.67 µm and a gap length of 187.6 ± 43.6 µm, while groups II and III showed a gap width of 12.4 ± 3.29 and 22.8 ± 5.76 µm, and a gap length of 387.2 ± 84.36 and 641.2 ± 122.6 µm respectively.

Conclusion: Within the limitations of this study and under the parameters used and from the resulting data collected, we can presume that the use of compatible components leads to significant micromovement when compared with the use of original ones.

Clinical significance: The use of compatible prosthetic components with original implants showed significant micromovements when compared with the use of abutment and implant from the same manufacturer. Clinically, the micromovements when associated with leakage leads to bone loss around the neck of the implant and later to peri-implantitis.

Keywords: Compatible, Gap, Implant–abutment interface, Micromovement.

How to cite this article: Berberi A, Maroun D, Kanj W, Amine EZ, Philippe A. Micromovement Evaluation of Original and Compatible Abutments at the Implant–abutment Interface. J Contemp Dent Pract 2016;17(11):907-913.

Source of support: Nil

Conflict of interest: None

[1,3]Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Lebanese University, Beirut, Lebanon

[2]Department of Periodontology, Faculty of Dental Medicine Saint Joseph's University, Beirut, Lebanon

[4,5]Department of Prosthodontics, Faculty of Dental Medicine Saint Joseph's University, Beirut, Lebanon

Corresponding Author: Antoine Berberi, Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Lebanese University, Beirut, Lebanon, Phone: +9613731173, e-mail: anberberi@gmail.com

INTRODUCTION

Dental implant therapy has been widely accepted as a successful procedure used to replace missing teeth in order to restore masticatory function[1] in both partial[2] and complete[3] edentulous cases. It was particularly shown to be successful in single-tooth replacements for both the anterior and posterior regions of the jaws.[4-6]

Most dental implant systems consist of two main parts: The implant body and the abutment.[7]

During chewing and biting, the restoration and the implant abutment connection is disturbed by various

physiological forces[8], e.g., the amount of force applied on a single molar implant reaches 847 N for men and 595 N for women on average.[9] Single-tooth prosthetic components are subjected to a higher bending moment during functional loading.[10]

For the majority of segmented implant systems, an implant–abutment assembly shows marginal discrepancies and microgaps at the implant–abutment interface.[11,12]

Microgaps at the implant–abutment interfaces can cause leakage[13,14] as microorganisms can penetrate through gaps as small as 10 µm.[15] Moreover, as the implant shoulder is located at the alveolar bone crest level, the bone–implant interface is exposed to inflammation,[16] infection,[17,18] and marginal bone loss.[18-22]

Micromovement is defined as a movement of a tooth, prosthesis, or implant system component below 100 µm that is not observable or subject to measurement *in vivo* by ordinary means.[23]

In most implant systems, the exchange of fluids, in both directions, takes place at the level of the marginal bone crest and is considered to be a factor for chronic inflammation and marginal bone loss.[18-22]

Thus, during function and under occlusal loading, micromovement between abutment and implant will create a volumetric variation in the inner volume of the implant system.[24-26]

Technical failure and bone resorption have been related to micromovements between abutments and implant body during dynamic load,[24,27] while implant fractures have been reported[28-31] as varying between 5 and 20%.[32] Interestingly, Zipprich,[32] in 2007, was able to measure the implant–abutment micromovement in an *in vitro* study while simulating clinical loading conditions. Implant–abutment connections were X-rayed during dynamic loading on an implant-supported simulated molar crown of the lower jaw, in order to obtain qualitative and quantitative recordings of any micromovements in real time.

An implant–abutment connection stability is important for the success of the restoration and is affected by factors, such as component fit, fabrication accuracy, saliva contamination, and screw load.[10-12,33-37] The design of abutment joints should be carefully matched with implant connection, since biomechanical assets depend on elements, such as materials, tolerance, connection design, and preload.[10,24,38-42] Regardless of several adverse mechanical complications that may occur even in cases where abutments and implants of a same brand have been used, such as increased incidence of abutment rotation[38-40,43,44] and screw loosening,[43-45] dental offices and/or dental laboratory have been accepting alternative solutions relating the use of nonoriginal or compatible abutments (i.e., abutments produced by a different manufacturer) in a strive to reduce expenses and the so-called overheads.

The aim of this study was to evaluate the mechanical behavior of OsseoSpeed™ implants connected with original and compatible abutments *in vitro* under simulated clinical conditions, by measuring the size of width and length of the microgaps.

The null hypothesis of the study was that there is no modification in micromovements when using original or compatible abutments.

MATERIALS AND METHODS

Implant and Abutments

A total of 15 OsseoSpeed™ Tx implants (4 × 11 mm, Astra Tech Implant System™, Dentsply Implants, Mölndal, Sweden) were used in this study. The samples were divided into three groups (n = 5).

Three types of abutments were used in the study and were all compatible with Astra Tech Implant System™ having the same internal implant–abutment connection interface, a conical-hex connection with 11° angulations. In this study, all items were prefabricated and used as delivered by the different manufacturers.

In group I, five original Ti Design™ abutments (4.5 × 1.5 mm, Astra Tech Implant System™, Denstply Implants, Mölndal, Sweden) were respectively connected to an OsseoSpeed™ Tx implant. In groups II and III, five Natea™ abutments (4.6 × 2 mm, Euroteknika™ Groupe, Sallanches, France) and five Implanet™ abutments (4 × 1.5 mm, Derig LTDA, Sao Paolo, Brazil) were connected to the same type of implants.

Assembly of the Abutments and Load Arrangement

The abutments were connected to implants with a calibrated torque wrench Torsiometer 760 (Stahlwille Group, 42331 Wuppertal, Germany) following the manufacturer's torque recommendations (20 N/cm for group I, 30 N/cm for group II and 30 N/cm for group III).

Implants were embedded into a resin mold with an elasticity module of approximately 2000 to 2300 N/mm^2, similar to that of bone (Technovit® 4004; Heraeus Kulzer GmbH, 61273 Wehrheim, Germany) and according to the dynamic fatigue testing for endosseous dental implants (DIN ISO 14801: 2006-2009), with a simulated bone resorption of 3 mm vertically.

Aluminum copings specially designed and fabricated were cemented to each abutment using autopolymerizing composites (3M Espe Nimetic™ Cern; Germany). The thread of each coping was sealed with a high-strength

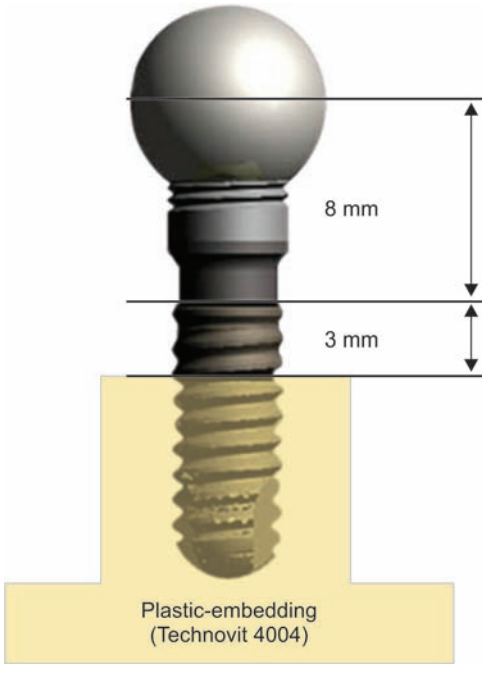

Fig. 1: Sample embedded in resin with ball cap for torque-free loading

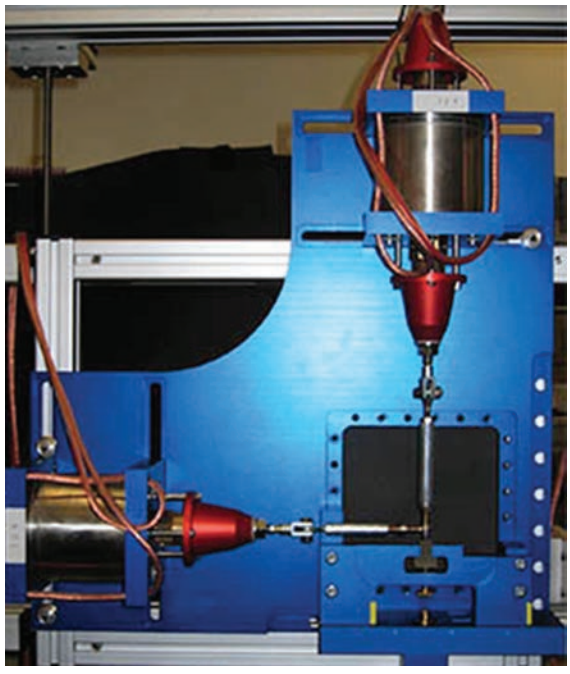

Fig. 2: The two-dimensional chewing simulator with the two motors

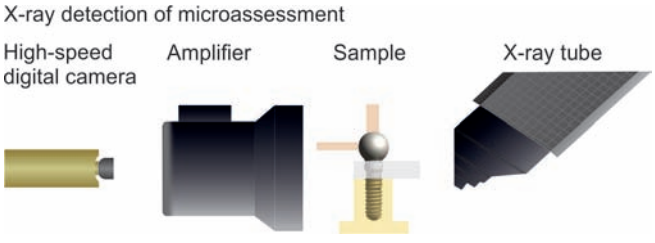

Fig. 3: The complete system

thread locker (Loctite 268, Henkel, Dusseldorf, Germany) to keep the force transfer position in the mastication simulator constant as seen in Figure 1.

A specially designed mastication simulator was used to apply two-dimensional (2D) masticatory forces on implant–abutment connections. The overall force acting on the abutment was generated by two motors that were perpendicular to each other.

Simulating the human masticatory cycle in the posterior segment and by analogy with DIN 148017, the axial force vector was increased to a defined maximum (25, 50, 75, 100, 125, 150, 175, and 200 N) and inclined 30° relative to the implant long axis. The force was introduced according to DIN 14801 at a distance of 8 mm from the implant shoulder as seen in Figure 2.

Dynamic recording of micromovements by X-ray videos is seen in Figure 3.

Source of X-ray and Radiograph Amplifier

The specimen was exposed to a constant and diverging X-ray to dynamically capture micromovements at the implant–superstructure connection (Phoenix X-ray system with a 160-kV tube, GE Sensing and Inspection Technologies GmbH Bogenstrasse 41, 22926 Ahrensburg, Germany).

A radiograph amplifier TH 9438 QX (Thales Group, Neuilly sur Seine, France) was used to convert the X-ray projection into a picture.

The X-ray, after entering the radiograph amplifier, meets an entrance of a fluorescent screen. Scintillation takes place, when the X-ray is converted into visible light. Directly behind the entrance to the fluorescence screen, a photocathode is present to set the electrons free through the arriving visible light. The electrons emitted by the photocathode are carried in an electrical field, starting from 60 keV potential differences, and bundled to a higher energy. Electrons, which are withdrawn from the radiograph amplifier, meet an output fluorescent screen, which exhibits a clearly smaller surface than the entrance screen. The electrons are made visible through the passage on the output screen. The amplification factor is indicated for this equipment at 200,000 light quanta per X-ray photon.

In addition, the very high image rate facilitates a smooth replay of the dynamic process in 40-fold slow motion. The pixel size was calibrated with a reference specimen for quantitative measurements of microgap widths and length. Automated pixel count surveyed microgaps in a window of width 4 µm.

High-speed Digital Camera

The radiograph amplifier follows a high-speed digital camera of the type Redlake Motion Pro® HS-3 (Redlake, Pennsylvania, USA).

This type of camera offers an integrated charge-coupled device sensor (load Couplet DEVICE sensor) that sends a digital signal proportional to the irradiated quantity of light to a computer. The digital camera used can achieve 1,000 pictures per second. By averaging each individual pixel, of several one behind the other noted pictures, the signal noise could be reduced. The number of pictures, which are charged with one another, is limited by the arising in-motion sharpness. The highest image quality was reached with the mean calculation of 11 successive pictures.

Evaluation

The load cycle determines the recording time of the camera. For the production of the X-ray video as "avi. file" with LabVIEW® (National Instruments Cooperation, Texas, USA), 276 pictures were used after calculations. The visual evaluation of the frames and the provided X-ray videos were evaluated for an existing microgap between implant and abutment. Existing cyclic openings and closings of the microgap could be made visible as seen in Figure 4. In order to measure the developed gap during and at its maximum load, a frame was determined. In this frame, each pixel inside the gap was counted. According to the resolution of the X-ray video, one pixel corresponds to 1.8 µm. Therefore, the exact size of the width and length of the microgaps was measured.

Statistical Analysis

Since the data distribution failed the normality test, Kruskal–Wallis test was used to compare the gap width (GW) and gap lenght (GL) between the five experimental groups at all the force levels. The level of significance was set at 0.05. When a significant difference was present, a Mann–Whitney *post hoc* test with a Bonferroni correction was used to detect which groups are significantly different from each other. Data were analyzed using the Statistical Package for Social Sciences (SPSS), version 21.0 (V7.0, IBM, Armonk, New York).

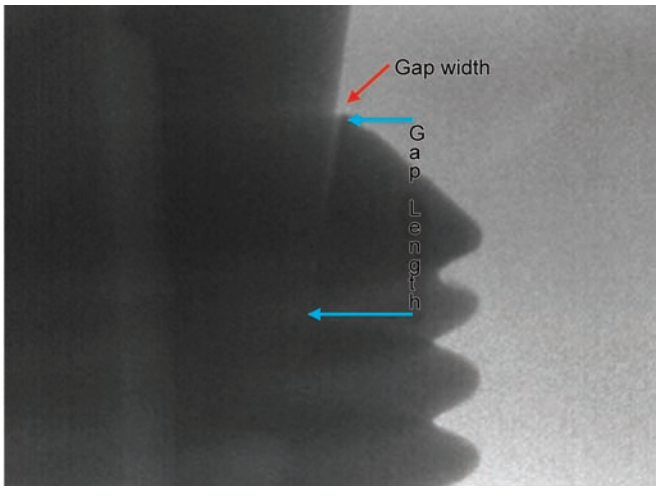

Fig. 4: Overview of implant–abutment assembly showing the gap width and gap length

RESULTS

For the three groups, the dynamic behavior for implant–abutment connections was studied under loading forces ranging between 25 and 200 N at 30° angle relative to the implant axis. The average results of the three groups in gap width and gap length are represented in Tables 1 and 2.

Before loading, no initial gap was observed in group I, while an initial gap was observed in groups II and III in four of the five samples with an average of 6.5 and 5 µm respectively. When forces of 25, 50, and 75 N were applied, no gap was observed in group I, while in group II, the gap length and gap width were both 5.2 ± 3.63 µm. In group III, at 25 and 50 N, both gap length and gap width remained at 4 ± 2.45 µm, while at 75 N the gap length was 4.8 ± 3.03 µm and the gap width 94 ± 125.3 µm.

At 100 N, group I showed a gap width of 1.2 ± 1.1 µm and a gap length of 24.4 ± 24.18 µm, while group II showed a gap width of 5.6 ± 2.97 µm and a gap length of 61.4 ± 122.3 µm and group III showed a gap width of 8 ± 4.69 µm and a gap length of 179.2 ± 141.1 µm.

Table 1: The average results of the three groups in gap width in relation to the applied forces

	Group I	*Group II*	*Group III*		
Force (n)	*Gap width (µm)*	*Gap width (µm)*	*Gap width (µm)*	*Chi-square*	*p-value*
25	0 ± 0	5.2 ± 3.63	4 ± 2.45	7.063	0.029
50	0 ± 0	5.2 ± 3.63	4 ± 2.45	7.063	0.029
75	0 ± 0	5.2 ± 3.63	4.8 ± 3.03	6.821	0.033
100	1.2 ± 1.1	5.6 ± 2.97	8 ± 4.69	6.278	0.043
125	2 ± 2	6.4 ± 2.61	10.8 ± 4.15	9.078	0.011
150	3.2 ± 1.79	7.2 ± 4.98	13.6 ± 3.85	9.444	0.009
175	6.4 ± 1.67	10.4 ± 3.29	18.4 ± 5.37	10.74	0.005
200	8.4 ± 1.67	12.4 ± 3.29	22.8 ± 5.76	11.32	0.003

Table 2: The average results of the three groups in gap length in relation to the applied forces

	Group I	*Group II*	*Group III*		
Force (n)	*Gap length (µm)*	*Gap length (µm)*	*Gap length (µm)*	*Chi-square*	*p-value*
25	0 ± 0	5.2 ± 3.63	4 ± 2.45	7.063	0.029
50	0 ± 0	5.2 ± 3.63	4 ± 2.45	7.063	0.029
75	0 ± 0	5.2 ± 3.63	94 ± 125.3	6.874	0.032
100	24.4 ± 24.18	61.2 ± 122.3	179.2 ± 141.1	3.047	0.218
125	34.8 ± 34.57	92.4 ± 111.7	267.2 ± 133	8.555	0.014
150	80.8 ± 54.95	165.6 ± 113.7	395.2 ± 123.8	9.62	0.008
175	126.4 ± 39.4	273.6 ± 78.36	542.4 ± 107.1	12.02	0.002
200	187.6 ± 43.6	387.2 ± 84.36	641.4 ± 122.6	12.5	0.002

In all three groups, gap length and gap width increased as the loading was increased to 125 and 150 N.

At 200 N, group I showed a gap width of 8.4 ± 1.67 µm and a gap length of 187.6 ± 43.6 µm, while group II had a gap width of 12.4 ± 3.29 µm and a gap length of 387.2 ± 84.36 µm and group III had a gap width of 22.8 ± 5.76 µm and gap length of 641.2 ± 122.6 µm.

DISCUSSION

The long-term success of implant prostheses is dependent on both biological and mechanical factors. In contrast to the high success rates of osseointegration (95–97%), mechanical complications are common in dental implantology.[32,46,47]

For fixed restorations, mechanical complications, such as screw loosening and screw fracture have been reported to be as high as 44.9%.[47-50]

Prevention of micromovements between implant–abutment is necessary in order to reduce inflammation and to reserve marginal bone at implant's neck connection. It still represents a major challenge for the design of two-stage implant systems, and factors, such as connection design, mechanical stability, precision of fit, and micromovement between components play crucial roles in maintaining marginal bone. Implant manufacturers aim to decrease the mobility of this connection by manufacturing of a substantially tight connection with a high precision at the submicrometer level. Nevertheless, high costs of such components lead dentists to use compatible and less expensive abutments.

The innovative evaluation method used in this study allowed for a quantitative measurement of the width and length gaps.

The results of the study led to the elimination of the null hypothesis tested, as there was a significant difference in micromovement between compatible and original abutments. The presence of an initial gap in groups II and III could be related to the reduced precision level and the quality control of materials used during the engineering process.

In group I, there were no micromovements detected between 25 and 75 N, while the microgap length reached was 5.2 ± 3.63 in group II and 94 ± 125.3 in group III at 75 N. At 100 N, the variation of micromovements between the three groups was statistically significant as it reached a variation of more than 250% between groups I and II and a variation of 400% between groups I and III. At 200 N, group I showed a gap width of 8.4 ± 1.67, while groups II and III showed a gap width of 12.4 ± 3.29 and 22.8 ± 5.76 respectively. It represented a variation of 48% between groups I and II and of 171% between groups I and III. For the gap length, a variation of 206% was reached between groups I and II and of 341% between groups I and III. The 200 N maximum load applied in this study was less than the reported data for maximum bite forces.[18] However, the results of the dynamic behavior showed a significant difference between compatible and original abutments.

In a previous study concerning leakage evaluation at implant–abutment interface of the three groups, when the combination OsseoSpeed™ Tx–TiDesign™ is considered as a control, OsseoSpeed™ Tx–Implanet™ presents 1113 and 782%, while OsseoSpeed™–Natea™ presents 640 and 481% fold increase at 1 and 48 hours respectively.[48]

The clinical incidence of mechanical complications varies among different implant systems.[39,40,43] Two factors associated with mechanical complications are joint stability and prosthetic fit.[49,50] Several studies on the connection design of the implant–abutment connection have established a relationship between micromovements and marginal bone loss.[12,15,16,19] The mismatch of the implant and the abutment surfaces can cause rapid stress, which ends up with loosening of screw,[45] microleakage,[13,14,48] and permanent offset.[22] Especially in single crowns, screw loosening is still the most frequently seen complication.[51,52]

CONCLUSION

Within the limitations of this *in vitro* study and under the parameters used and from the resulting data collected, we can presume that the use of compatible abutment components with original Astra Tech implants showed significant micromovement when compared with the use of abutment and implant from the same manufacturer.

Compatible abutments vary in the design of surfaces, dimensions, profile, and material and have showed higher micromovement values. The differences in design may be related to patent issues that do not permit exact replication of components and/or related to the precision level in the engineering process. Further investigations are needed to validate these findings to other systems and assess the differences after simulated clinical function.

ACKNOWLEDGMENT

Authors would like to thank Mr Holger Zipprich and Dr Christopher Ratka (Center for Dental and Oral Medicine and Cranio-Maxillofacial Surgery, Frankfurt University) for their valuable help in the testing of the products and Dr Maria Saadeh for the statistical analyses.

REFERENCES

1. Vieira RA, Melo AC, Budel LA, Gama JC, de Mattias Sartori IA, Thomé G. Benefits of rehabilitation with implants in masticatory function: is patient perception of change in accordance with the real improvement? J Oral Implantol 2014 Jun;40(3):263-269.

2. van Eekeren PJ, Aartman IH, Tahmaseb A, Wismeijer D. The effect of implant placement in patients with either Kennedy class II and III on oral health-related quality of life: a prospective clinical trial. J Oral Rehabil 2016 Apr;43(4): 291-296.
3. Millen C, Brägger U, Wittneben JG. Influence of prosthesis type and retention mechanism on complications with fixed implant-supported prostheses: a systematic review applying multivariate analyses. Int J Oral Maxillofac Implants 2015 Jan-Feb;30(1):110-124.
4. Donati M, Ekestubbe A, Lindhe J, Wennström JL. Implant-supported single-tooth restorations. A 12-year prospective study. Clin Oral Implants Res 2016 Oct;27(10):1207-1211.
5. Berberi AN, Sabbagh JM, Aboushelib MN, Noujeim ZF, Salameh ZA. A 5-year comparison of marginal bone level following immediate loading of single-tooth implants placed in healed alveolar ridges and extraction sockets in the maxilla. Front Physiol 2014;5:29.
6. Mezzomo LA, Miller R, Triches D, Alonso F, Shinkai RS. Meta-analysis of single crowns supported by short (<10 mm) implants in the posterior region. J Clin Periodontol 2014 Feb;41(2):191-213.
7. Mish CE. Contemporary implant dentistry. 3rd ed. St. Louis, MO: Mosby Elsevier; 2008.
8. Richter EJ. *In vivo* vertical forces on implants. Int J Oral Maxillofac Implants 1995 Jan-Feb;10(1):99-108.
9. Waltimo A. Studies on human bite force. A novel bite force recorder and its clinical applications. Prosthetic Dentistry. Helsinki: Med.-Habilitation; 1995.
10. Lee FK, Tan KB, Nicholls JI. Critical bending moment of four implant-abutment interface designs. Int J Oral Maxillofac Implants 2010 Jul-Aug;25(4):744-751.
11. Binon PP, McHugh JM. The effect of eliminating implant/abutment rotational misfit on screw joint stability. Int J Prosthodont 1996 Nov-Dec;9(6):511-519.
12. Khraisat A, Abu-Hammad O, Al-Kayed AM, Darodeh N. Stability of the implant/abutment joint in a single-tooth external hexagon implant system: clinical and mechanical review. Clin Implant Dent Relat Res 2004;6(4):222-229.
13. Harder S, Dimaczek B, Acil 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):427-432.
14. Harder S, Quabius ES, Ossenkop L, Kern M. Assessment of lipopolysaccharide microleakage at conical implant-abutment connections. Clin Oral Investig 2012 Oct;16(5):1377-1384.
15. Broggini N, McManus LM, Hermann JS, Medina RU, Oates TW, Schenk RK, Buser D, Mellonig JT, Cochran DL. Persistent acute inflammation at the implant-abutment interface. J Dent Res 2003 Mar;82(3):232-237.
16. Hermann JS, Schoolfield JD, Schenk RK, Buser D, Cochran DL. Influence of the size of the microgap on crestal bone changes around titanium implants. A histometric evaluation of unloaded non-submerged implants in the canine mandible. J Periodontol 2001 Oct;72(10):1372-1383.
17. King GN, Hermann JS, Schoolfield JD, Buser D, Cochran DL. Influence of the size of the microgap on crestal bone levels in non-submerged dental implants: a radiographic study in the canine mandible. J Periodontol 2002 Oct;73(10):1111-1117.
18. Adell R, Lekholm U, Rockler B, Brånemark PI, Lindhe J, Eriksson B, Sbordone L. Marginal tissue reactions at osseointegrated titanium fixtures (I). A 3-year longitudinal prospective study. Int J Oral Maxillofac Surg 1996 Feb;15(1):39-52.
19. Albrektsson T, Buser D, Sennerby L. On crestal/marginal bone loss around dental implants. Int J Periodontics Restorative Dent 2013 Jan-Feb;33(1):9-11.
20. Guindy JS, Besimo CE, Besimo R, Schiel H, Meyer J. Bacterial leakage into and from prefabricated screw-retained implant-borne crowns *in vitro*. J Oral Rehabil 1998 Jun;25(6):403-408.
21. Quirynen M, deSoete MD, van Steenberghe D. Infectious risks for oral implants: a review of the literature. Clin Oral Implants Res 2002 Feb;13(1):1-19.
22. Zipprich H, Weigl P, Lange B, Lauer HC. Micromovements at the implant-abutment interface: measurement, causes and consequences. Implantologie 2007;15(1):31-46.
23. Orsini G, Fanali S, Scarano A, Petrone G, di Silvestro S, Piattelli A. Tissue reactions, fluids, and bacterial infiltration in implants retrieved at autopsy: a case report. Int J Oral Maxillofac Implants 2000 Mar-Apr;15(2):283-286.
24. Proff P, Steinmetz I, Bayerlein T, Dietze S, Fanghänel J, Gedrange T. Bacterial colonisation of interior implant threads with and without sealing. Folia Morphol 2006 Feb;65(1):75-77.
25. Kinsel RP, Lamb RE. Tissue-directed placement of dental implants in the esthetic zone for long-term biologic synergy: a clinical report. Int J Oral Maxillofac Implants 2005 Nov-Dec; 20(6):913-922.
26. Adell R, Leckholm U, Rockler B, Brånemark P-I. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981 Dec;10(6):387-416.
27. Jimbo R, Halldin A, Janda M, Wennerberg A, Vandeweghe S. Vertical fracture and marginal bone loss of internal-connection implants: a finite element analysis. Int J Oral Maxillofac Implants 2013 Jul-Aug;28(4):e171-176.
28. Rangert B, Krogh PH, Langer B, van Roekel N. Bending overload and implant fracture: a retrospective clinical analysis. Int J Oral Maxillofac Implants 1995 May-Jun;10(3):326-334.
29. Eckert SE, Meraw SJ, Cal E, Ow RK. Analysis of incidence and associated factors with fractured implants: a retrospective study. Int J Oral Maxillofac Implants 2000 Sep-Oct;15(5):662-667.
30. Berglundh T, Persson L, Klinge B. A systematic review of the incidence of biological and technical complications in implant dentistry reported in prospective longitudinal studies of at least 5 years. J Clin Periodontol 2002;29 (Suppl 3):197-212.
31. Gigandet M, Bigolin G, Faoro F, Bürgin W, Brägger U. Implants with original and non-original abutment connections. Clin Implant Dent Relat Res 2014 Apr;16(2):303-311.
32. Zipprich H. Failure mode of implant-abutment connections after horizontal cyclic loading. J Dent Oral Med 2004;6(3):238.
33. Jorneus L, Jemt T, Carlsson L. Loads and designs of screw joints for single crowns supported by osseointegrated implants. Int J Oral Maxillofac Implants 1992 Fall;7(3): 353-359.
34. Norton MR. Assessment of cold welding of the internal conical interface of two commercially available implant systems. J Prosthet Dent 1999 Feb;81(2):159-166.
35. Schwarz MS. Mechanical complications of dental implants. Clin Oral Implants Res 2000;11 (Suppl 1):156-158.
36. Nikopoulou F. Saliva and dental implants. Implant Dent 2006 Dec;15(4):372-374.
37. Mc Glumphy EA. Implant screw mechanics. Dent Clin North Am 1998 Jan;42(1):71-89.

38. Gratton DG, Aquilino SA, Stanford CM. Micromotion and dynamic fatigue properties of the dental implant-abutment interface. J Prosthet Dent 2001 Jan;85(1):47-52.
39. Khraisat A, Stegaroiu R, Nomura S, Miyakawa O. Fatigue resistance of two implant/abutment joint designs. J Prosthet Dent 2002 Dec;88(6):604-610.
40. Meng JC, Everts JE, Qian F, Gratton DG. Influence of connection geometry on dynamic micromotion at the implant-abutment interface. Int J Prosthodont 2007 Nov-Dec;20(6):623-625.
41. Dixon DL, Breeding LC, Sadler JP, McKay ML. Comparison of screw loosening, rotation, and deflection among three implant designs. J Prosthet Dent 1995 Sep;74(3):270-278.
42. Esposito M, Hirsch JM, Lekholm U, Thomsen P. Biological factors contributing to failures of osseointegrated oral implants. (II) Etiopathogenesis. Eur J Oral Sci 1998 Jun;106(3):721-764.
43. Byrne D, Houston F, Cleary R, Claffey N. The fit of cast and premachined implant abutments. J Prosthet Dent 1998;80:184-192.
44. Binon PP. Implants and components: entering the new millennium. Int J Oral Maxillofac Implants 2000 Jan-Feb;15(1): 76-94.
45. al-Turki LE, Chai J, Lautenschlager EP, Hutten MC. Changes in prosthetic screw stability because of misfit of implant-supported prostheses. Int J Prosthodont 2002 Jan-Feb;15(1): 38-42.
46. Carr AB, Brunski JB, Hurley E. Effects of fabrication, finishing, and polishing procedures on preload in prostheses using conventional "gold" and plastic cylinders. Int J Oral Maxillofac Implants 1996 Sep-Oct;11(5):589-598.
47. Loza-Herrero MA, Rivas-Tumanyan S, Morou-Bermudez E. Success and complications of implant-retained prostheses provided by the Post-Doctoral Prosthodontics Program, University of Puerto Rico: a cross-sectional study. J Prosthet Dent 2015 Nov;114(5):637-643. Epub 2015 Jul 31.
48. Berberi A, Tehini G, Rifai K, Bou Nasser Eddine F, Badran B, Akl H. Implants with original and compatible abutment connections: *in vitro* leakage evaluation using Rhodamine B. J Dent Biomech 2014 Aug;5:1758736014547143.
49. Kallus T, Bessing C. Loose gold screws frequently occur in full-arch fixed prostheses supported by osseointegrated implants after 5 years. Int J Oral Maxillofac Implants 1994 Mar-Apr;9(2):169-178.
50. Pjetursson BE, Brägger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clin Oral Implants Res 2007 Jun;18 (Suppl 3): 97-113.
51. Jung RE, Pjetursson BE, Glauser R, Zembic A, Zwahlen M, Lang NP. A systematic review of the 5-year survival and complication rates of implant-supported single crowns. Clin Oral Implants Res 2008 Feb;19(2):119-130.
52. Sakaguchi RL, Borgersen SE. Nonlinear contact analysis of preload in dental implant screws. Int J Oral Maxillofac Implants 1995 May-Jun;10(3):295-302.