

# Changes in the Abutment/Implant Interface in Morse Taper Implant Connections After Mechanical Cycling: A Pilot Study

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**Purpose:** The aim of this study was to measure and compare, using scanning electron microscopy, the implant-abutment interface of a Morse taper system before and after cyclic loading. **Materials and Methods:** Four Morse cone implants and four solid abutments were used. These abutments had been machined to reduce the diameter of the part corresponding to the site of prosthesis cementation. They were then screwed onto the implants and torqued to 25 N. Under a scanning electron microscope, 32 images (16 before and 16 after cycling) of the interfaces were obtained under  $\times 1,000$  and  $\times 5,000$  magnification. The samples were subjected to 345,600 cycles with a fatigue testing machine, in which the applied load was 80 N and the frequency was 4 Hz, to simulate chewing. With appropriate software (Image Tool 3.0), the marginal gaps of the interfaces before and after load cycling were measured. The data were analyzed with the Student t test at a significance level of 5%. **Results:** Significant differences were found between interfaces before and after cycling. Prior to mechanical cycling, the Morse taper implant/abutment assemblies exhibited an average gap size of  $3.34 \pm 2.17$  mm, whereas the average gap size after mechanical cycling was  $1.35 \pm 0.64$   $\mu\text{m}$ . **Conclusion:** After mechanical cycling, there was a significant decrease in the size of the gap, which indicated better adaptation and sealing ability at the level of the microgap. INT J ORAL MAXILLOFAC IMPLANTS 2014;29:xxx-xxx. doi: 10.11607/jomi.3113

**Key words:** abutment, cyclic loading, dental implant, implant-abutment gap, Morse taper

The prognosis regarding the longevity of dental implant treatment is predictable, and when placed in ideal positions, with adequate prosthesis design and proper maintenance, implants can achieve success rates of 97% to 99%, with outstanding long-term functional performance.<sup>1-3</sup> The vast majority of studies indicate satisfactory success with implant-supported prostheses<sup>4-7</sup>; however, in longitudinal clinical evaluations, mechanical and microbiologic complications have been reported,<sup>4,8,9</sup> which can loosen the abutments<sup>10</sup> and damage the implants and the supporting tissues.<sup>11</sup> The leakage of microorganisms and fluids to the inner part of the implant is considerably increased by load application, which generates

micromovements and interfacial gaps<sup>12</sup> and can thus lead to peri-implantitis.<sup>13</sup>

The significance of the existence and location of a microgap between implant components is poorly understood.<sup>14</sup> The reason for the reaction to the presence of a microgap is not known, but, as already pointed out, it could be related to the presence of contamination by bacteria at the implant-abutment interface or to micromovements at the interface.<sup>15</sup> Gaps and cavities have been described in two-piece implants, even when good marginal fit of the implant components is present. These hollow spaces can serve as traps for bacteria, which might then lead to inflammation in the peri-implant soft tissues.<sup>16-19</sup> Bacterial leakage at the junction between the abutment and the implant, as well as along the abutment screw, has been reported.<sup>17</sup> The microorganisms found inside the implants might be associated with the bone loss that is typically observed during the first year after implant placement.<sup>19,20</sup> The gap generated by this misfit can also act as a trap for bacteria colonization, which might cause inflammatory reactions in the peri-implant soft tissues.<sup>21-23</sup>

In the oral cavity, masticatory forces act on the prosthetic restorative materials to promote cyclic mechanical impulses, which can be partly simulated in the

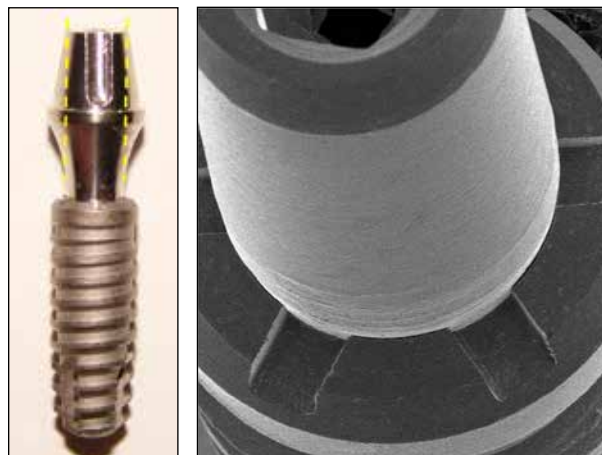
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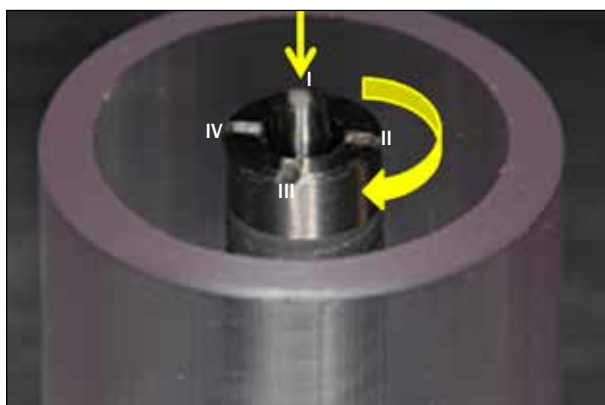
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**Fig 1** (Left) The Morse cone implant used and (right) the original dimensions and form of the abutment.



**Fig 2** (Left) The abutment/implant assembly before machining and (right) after machining to reduce the body of the abutment. The yellow lines show the portion of the abutment that was removed.



**Fig 3** View of the marks made on the implant platform to determine the locations of images acquired by SEM, starting at the position identified by the yellow arrow and continuing clockwise.

laboratory by mechanical cycling machines, which attempt to mimic the physiologic conditions found during chewing. Thus, this pilot study aimed to examine, through scanning electron microscopy (SEM) images, the behavior of the existing gap in the implant-abutment interface of Morse taper implants after mechanical cycling.

## MATERIALS AND METHODS

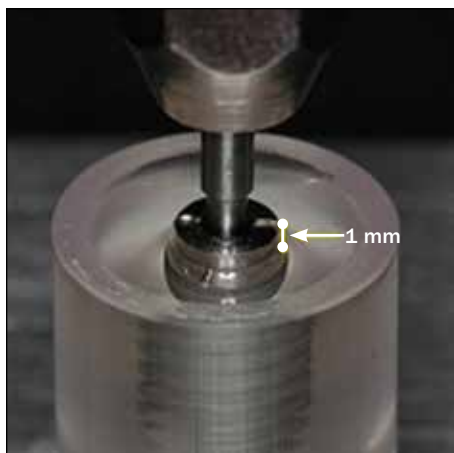
For this research, four dental implants with a Morse taper connection (Implacil De Bortoli) with a diameter of 4.0 mm and a length of 11 mm were used (Fig 1a). Since this is a pilot study, the number of samples was determined by the ability of the test equipment

to work with four pieces simultaneously. Four straight abutments were used; these comprised a 3.5-mm-long transmucosal portion, a 4.0-mm-high baseplate prosthetic, and a 4.5-mm-diameter platform (Fig 1b).

The junction between the abutment and a Morse taper implant is situated on the platform of the implant, providing the effect of platform switching. After emerging from the implant at 2.3 mm in diameter, the abutment increases in diameter to create an emergence profile that reaches 4.5 mm in diameter. Thus, it is possible to analyze this gap through direct visualization; images can be obtained from above, looking into the interface of the implant/abutment, so that the abutments can be machined to reduce their diameter, thereby removing this emergence profile (Figs 2a and 2b). This procedure was carried out in the machining division of the Implacil De Bortoli factory on a computerized lathe (Cincom C16 1M7A, Citizen) to ensure accuracy in the preparation of samples, which was done at low speed and with abundant irrigation to prevent changes in the metal structures. After machining, the upright abutments were washed with water in an ultrasonic tank for 20 minutes to remove residues from the cutting process.

The entire surface of the abutment/implant in the implant platform was marked with a high-speed drill to identify four points (I, II, III, and IV) that divided the circumference of the implant platform into four equal parts. Marking of the locations of these lines, from which the images were obtained, was randomized (Fig 3). The images were always captured in a clockwise direction.

After these procedures, the implants were fixed in a vise, and the abutments were inserted with an applied torque of 25 Ncm, as recommended by the manufacturer, with an analog torque wrench (BTG 60 CN – S,



**Fig 4** The paralleling device used to position the resin sets; the yellow line represents the final distance from the resin to the implant platform.



**Fig 5** (a) The polyacetal tip manufactured for testing. (b) The piston contact with the specimen, which was immersed in saline solution at a temperature of 37°C.

Tohnichi). After 10 minutes of initial torque application, a further application of torque (with the same intensity as the initial torque) was performed to minimize the effect of settling and aid in the maintenance of an optimal preload, as suggested by others.<sup>24</sup> Images of the four samples were then obtained under an SEM (JSM 5310, Jeol) at magnifications of  $\times 1,000$  and  $\times 5,000$ .

For the fatigue testing, four polyvinyl cylinders were fabricated at a height of 15 mm, an external diameter of 15 mm, and an inner diameter of 12 mm. The abutment/implant assemblies were placed into these cylinders with the aid of polyacetal guides, and a positioning device with vertical rods, which allowed for the engagement of the ends of the polyacetal guide, was used to center the sets with regard to the vertical and horizontal axes.

With the sets centered, the resin was manipulated according to the instructions of the manufacturer. After the resin was mixed, the polyvinyl cylinders were filled with the resin to approximately 1 mm below the platform of the implant (Fig 4). This type of resin has a tensile modulus of  $0.21 \times 10^9$  N/m<sup>2</sup>, similar to the elastic modulus of human trabecular bone ( $0.14 \times 10^9$  N/m<sup>2</sup>).<sup>25</sup>

Final polymerization of the resin occurred within 72 hours in an oven at a controlled temperature of 60°C, after which the specimens were disconnected from the positioning devices. The fatigue tests of the four specimens were performed at the Department of Dental Materials, School of Dentistry, University of São Paulo in a mechanical cycling machine (Bio PDI, Biocycle). This machine had four pistons that were equipped with polyacetal tips (Fig 5), so that no direct impact occurred between the two metal surfaces.

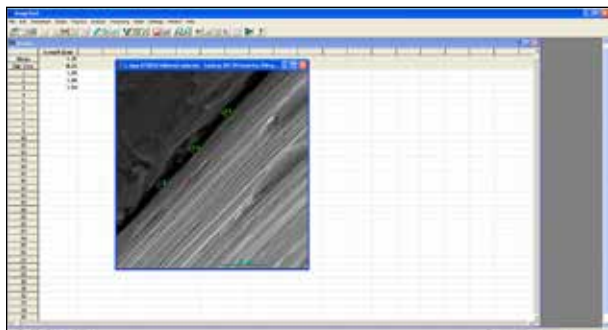
In the tests, 345,600 cycles were applied with a frequency of 4 Hz and a sinusoidal force of 80 N, which

was representative of approximately 14 months of function. This load corresponds to median functional masticatory forces (about 60 to 100 N).<sup>26</sup> The tests were performed with the specimens immersed in saline at approximately 37°C; this was automatically controlled and maintained by a thermostat connected to the bottom of each recipient in each sample. The load was applied in the direction of the long axis of the abutment/implant assembly.

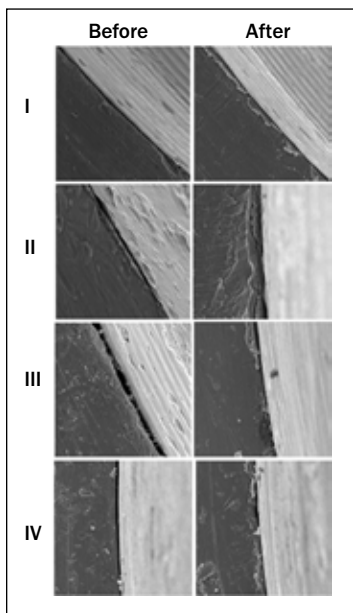
Upon completion of the programmed cycles, new images were obtained under SEM in the same positions as described earlier. In this process, the samples were placed in water in an ultrasonic vat for 20 minutes to remove any undesirable residue, and they were subsequently sputter coated with gold (Denton Accum Desk II) to enhance the SEM images because of the presence of resin in the samples.

In each set, four images were obtained in the equidistant positions shown in Fig 2. The observations were made in the four different areas of all four implants; thus, 16 images at  $\times 1,000$  magnification and 16 images at  $\times 5,000$  were obtained before cycling. After testing, 32 additional images were obtained (16 images at  $\times 1,000$  magnification and 16 at  $\times 5,000$  magnification after cycling), resulting in a total of 64 images for analysis.

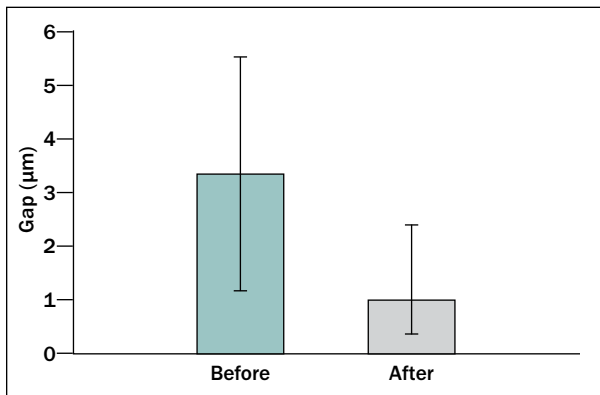
The images at the abutment/implant interface obtained under  $\times 5,000$  magnification ( $n = 32$ ) were used for measurements (quantitative analysis), which were performed with Image Tool (version 3.0 for Windows, University of Texas Health Science Center, San Antonio). These measurements were made at three points on each gap image (Fig 6): one in the center of each image and the other two on each side, 7  $\mu$ m from the center point. The average of these three measures was used as the reported value for each gap.



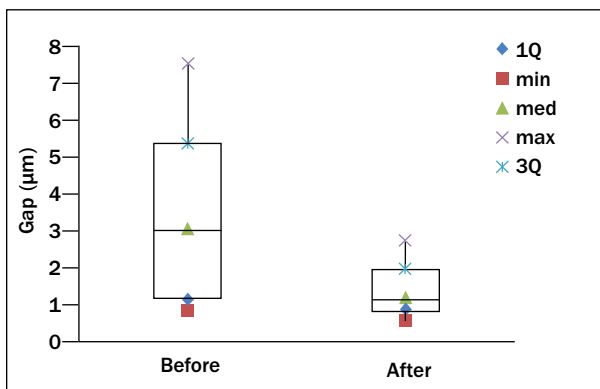
**Fig 6** Image of the measured gap in one of the samples, where L1 = the right measurement; L2 = the central measurement; L3 = the left measurement.



**Fig 7** Images of sets I, II, III, and IV taken at  $\times 1,000$  magnification. It is evident that the implant-abutment gaps decreased after mechanical cycling.



**Fig 8** Comparison of the average gaps (with standard deviations) in the samples before and after mechanical cycling.



**Fig 9** Comparisons of the sizes of the gaps measured in the four sets before and after mechanical cycling. 1Q = first quartile; min = minimum; med = median; max = maximum; 3Q = third quartile.

Statistical analysis of the collected data was performed using the Student *t* test.

## RESULTS

Results are presented in a qualitative manner based on comparative evaluation of the images and quantitative measurements of the interfaces. For the qualitative analysis of the gaps, the images taken at  $\times 1,000$  magnification were used, whereas the images obtained at  $\times 5,000$  magnification were used for statistical analysis (quantitative).

### Qualitative Analysis of the Gaps

When the images were compared, it was evident that, after cycling, there was an approximation between the walls of the implant and the abutment that reduced the existing gap initially. More “barbs” were present on the abutments, suggesting that there was deformation

of the abutment and intrusion (via loading) into the implant. This increased friction between the walls of these components increased the degree of union, which is also called “cold soldering.” The differences in the interface before and after cycling are apparent from the images, which reveal a decrease in the size of the interface after mechanical cycling (Fig 7).

### Quantitative Analysis of the Gaps

The measurements of the implant/abutment gaps were tabulated in a spreadsheet, and the average measurements were obtained from each quadrant. These data were used to generate a chart comparing the gaps measured before and after mechanical cycling (Fig 8).

### Statistical Analysis

The average preload size of the gap was  $3.34 \pm 2.17$   $\mu\text{m}$ , and the average size of the gap after loading was  $1.35 \pm 0.64$   $\mu\text{m}$ , illustrating a decrease in the cracks

after cycling, which simulated mastication. After analysis of the second graph (Fig 9), it became evident that there was a decrease in the sizes of the gaps between the abutments and implants after mechanical cycling. The differences in the mean sizes of the analyzed gaps were significant ( $P = .0006$ ).

## DISCUSSION

Most dental implant systems consist of two parts, so that the implant receives a prosthetic component, and a bonding interface is created at which larger or smaller gaps between their walls can exist, depending on the degree of fit between the two parts.<sup>4</sup> These gaps increase the mechanical stress on the connecting structures and the surrounding bone tissue, and they may also lead to a loss of preload or to screw fracture, resulting in various biologic outcomes.<sup>27,28</sup> Moreover, microgaps at the implant/abutment interface induced by an ill-fitting connection may allow bacteria to penetrate and colonize the inner part of the implant, facilitating inflammatory processes.<sup>27-29</sup>

Failures are more frequent in prosthetic tooth restorations, and most often consist of loosening and/or fracture of the screws retaining the abutment.<sup>9,30,31</sup> Such failures can result in discomfort for the patient, additional chair time to resolve the problem, peri-implant tissue reactions,<sup>31</sup> bone loss around the implant, and even fracture of the implant components.<sup>32</sup> Several clinical and laboratory studies have established the main causes, solutions, and clinical implications of the loosening of abutment screws; these publications have also addressed other types of implant/abutment connections,<sup>33,34</sup> the surface treatment of the screws, the optimization of sedimentation and increases in preload, and the suitability of various occlusal loads on implants.<sup>32</sup>

At present, conical connections exhibit the best performance from a biologic and mechanical point of view as a result of the improved fit between the implant and abutment. However, the ideal implant/abutment connection, which would eliminate the risk of bacterial penetration, has not yet been implemented.<sup>4,35,36</sup> To facilitate the development of a high-quality seal against bacteria, a large number of studies have focused on the penetration of microorganisms through microgaps in the implant/abutment interface. The majority of these papers have studied this seal under static conditions in vitro, without considering in vivo temperature variations and chewing stresses.<sup>4,27,35</sup>

The smaller the interference between the seating of the prosthetic abutment and the inner surface of the Morse taper implant, the higher the removal torque of the prosthetic component will be. This ensures that

the gaps recorded in the abutment/implant system are evaluated as having a favorable connotation, and it ensures the highest amount of imbrication in the mechanical portion of the conical prosthetic abutment.<sup>36</sup> This is the likely explanation for the number of clinical studies that have reported high rates of successful restoration of two-stage Morse taper implants.<sup>37,38</sup>

There are only a few studies, usually concerned with butt-joint connections, that examine the possibilities of direct in vitro observation using microradiography, SEM, optical microscopy, laser scanning microscopy, or theoretical approaches through finite element modeling.<sup>39,40</sup> Although many authors have reported a perfect fit with regard to conical connections, a recent study that used direct in vitro observation of conical coupling through hard x-ray synchrotron radiation demonstrated the presence of a microgap.<sup>39</sup> Additionally, recent leakage tests have demonstrated that this geometry cannot result in a perfect seal.<sup>39,40</sup>

However, the literature lacks studies that relate the size of the gap at the implant-abutment interface of the Morse taper connection before and after mechanical cycling using SEM. Fatigue tests have attempted to simulate the masticatory load to determine the stability of the interface, but most studies have employed different methodologies to apply these loads, ie, variations in the number of load cycles used, the frequency, the applied forces, the site, the form of load application, and the temperature, among others, have been used.<sup>33,41</sup> The protocol for the study of load values and the frequency of simulated masticatory cycles had its foundation in the work of other authors.<sup>33,41</sup>

The results of this analysis demonstrated the existence of gaps, similar to those described in the literature, which varied between 2 and 9  $\mu\text{m}$  for implants prior to the application of loads. These values were decreased significantly after mechanical loading, which shows that the clamping force between the components is increased by chewing, which promotes compressive intrusion forces<sup>42</sup> and reduces the possibility of failures in the system; these results are similar to those of other studies.<sup>29,43</sup> However, bacterial penetration at this location, on the basis of the averages obtained and demonstrated, is possible, knowing that the pathogens vary in their size. For example, *Actinobacillus actinomycetemcomitans*, which is a gram-negative organism that is  $0.7 \pm 1 \mu\text{m}$  in diameter and  $1 \pm 0.4 \mu\text{m}$  long,<sup>44</sup> could penetrate and produce fluid/toxins at the site, perhaps with much less intensity for reducing the population in this space. **[AU: Not sure what is meant by the phrase "perhaps with much less intensity for reducing the population in this space." Do you mean "perhaps giving another reason to reduce the size of the implant/abutment gap"? Please clarify.]**

This paper proposes the future use of in vitro direct observation by SEM of Implacil De Botroli Morse taper implant systems to detect possible microgaps that are visible within the magnifications adopted for acquisition and to examine the implant/abutment contact surfaces. Moreover, statistically significant differences were found between the surface data collected before and after the application of loads on implants.

## CONCLUSION

From the obtained results, it can be concluded that after mechanical cycling, there was a significant decrease in the gap at the abutment/implant interface, which was probably a result of intrusion and deformation of the abutment. Thus, within the limitations of this pilot study, although a small sample was used, the forces of mastication can improve the retention of the abutment on an implant by increasing the friction between the walls of these components, reducing the probability of micromotion between the parts and hence the possibility of abutment loosening.

## ACKNOWLEDGMENTS

The authors reported no conflicts of interest related to this study.

## REFERENCES

- Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg* 1981;10(6):387–416.
- Lindquist LW, Carlsson GE, Jemt T. A prospective 15-year follow-up study of mandibular fixed prostheses supported by osseointegrated implants. Clinical results and marginal bone loss. *Clin Oral Implants Res* 1996;7(4):329–336.
- Ekelund JA, Lindquist LW, Carlsson GE, Jemt T. Implant treatment in the edentulous mandible: A prospective study on Brånemark system implants over more than 20 years. *Int J Prosthodont* 2003;16(6):602–608.
- Piattelli A, Scarano A, Paolantonio M, et al. Fluids and microbial penetration in the internal part of cement-retained versus screw-retained implant-abutment connections. *J Periodontol* 2001;72(9):1146–1150.
- Sandberg G, Stenberg T, Wikblad K. Ten years of patients' experiences with fixed implant supported prostheses. *J Dent Hyg* 2000;74(3):210–218.
- Roos J, Sennerby L, Lekholm U, Jemt T, Gröndahl K, Albrektsson T. A qualitative and quantitative method for evaluating implant success: A 5-year retrospective analysis of the Brånemark implant. *Int J Oral Maxillofac Implants* 1997;12(4):504–514.
- Att W, Stappert C. Implant therapy to improve quality of life. *Quintessence Int* 2003;34(8):573–581.
- 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. *Clin Oral Implants Res* 2002;29(3):197–212.
- Brägger U, Karoussis I, Persson R, Pjetursson B, Salvi G, Lang NP. Technical and biological complications/failures with single crowns and fixed partial dentures on implants: A 10-year prospective cohort study. *Clin Oral Implants Res* 2005;16(3):326–334.
- Ekfeldt A, Christiansson U, Eriksson T, et al. A retrospective analysis of factors associated with multiple implant failures in maxillae. *Clin Oral Implants Res* 2001;12(5):462–467.
- King GN, Hermann JS, Schoolfield JD, Buser D, Cochran DL. Influence of the size of the microgap on crestal bone levels on non-submerged dental implants. A radiograph study in the canine mandible. *J Periodontol* 2002;73(10):1111–1117.
- Khraisat A, Baqain ZH, Smadi L, Nomura S, Miyakawa O, Elnesser Z. Abutment rotational displacement of external hexagon implant system under lateral cyclic loading. *Clin Implant Dent Relat Res* 2006;8(2):96–99.
- Gross M, Abramovich I, Weiss EI. Microleakage at the abutment-implant interface of osseointegrated implants: A comparative study. *Int J Oral Maxillofac Implants* 1999;14(1):94–100.
- Hermann JS, Cochran DL, Nummikoski PV, Buser D. Crestal bone changes around titanium implants: A radiographic evaluation of unloaded nonsubmerged and submerged implants in the canine mandible. *J Periodontol* 1997;68(11):1117–1130.
- Hermann JS, Buser D, Schenk RK, Higginbottom FL, Cochran DL. Biological width around titanium implants. A physiologically formed and stable dimension over time. *Clin Oral Implants Res* 2000;11(1):1–11.
- Persson LG, Lekholm U, Leonhardt A, Dahlen G, Lindhe J. Bacterial colonization on internal surfaces of Brånemark system implant components. *Clin Oral Implants Res* 1996;7(2):90–95.
- Quirynen M, Bollen CM, Eysen H, van Steenberghe D. Microbial penetration along the implant components of the Brånemark system. An in vitro study. *Clin Oral Implants Res* 1994;5(4):239–244.
- Jansen VK, Conrads G, Richter EJ. Microbial leakage and marginal fit of the implant-abutment interface. *Int J Oral Maxillofac Implants* 1997;12(4):527–540.
- Quirynen M, van Steenberghe D. Bacterial colonization of the internal part of two-stage implants. An in vivo study. *Clin Oral Implants Res* 1993;4(3):158–161.
- Ericsson I, Nilner K, Klinge B, Glantz P-O. Radiographical and histological characteristics of submerged and non-submerged titanium implants. An experimental study in the Labrador dog. *Clin Oral Implants Res* 1996;7(1):20–26.
- Abrahamsson I, Berglundh T, Glantz P-O, Lindhe J. The mucosal attachment at different abutments: an experimental study in dogs. *J Clin Periodontol* 1998;25(9):721–727.
- Jansen VK, Conrads G, Richter E-J. Microbial leakage and marginal fit of the implant-abutment interface. *Int J Oral Maxillofac Implants* 1997;12(4):527–540.
- Traversy MC, Birek P. Fluid and microbial leakage of implant-abutment assembly in vitro. *J Dent Res* 1992;71(3):754. **[AU: Is this an abstract or a 1-page article? If not, please provide ending page number of the cited article.]**
- Siamos G, Winkler S, Boberick KG. The relationship between implant preload and screw loosening on implant-supported prostheses. *J Oral Implantol* 2002;28(2):67–73.
- Quek CE, Tan KB, Nicholls JI. Load fatigue performance of a single-tooth implant abutment system: Effect of diameter. *Int J Oral Maxillofac Implants* 2006;21(6):929–936.
- Waltimo A, Kononen M. A novel bite force recorder and maximal isometric bite forces values for healthy young adults. *Scand J Dent Res* 1993;101(3):171–175.
- Ricomini Filho AP, Fernandes FS, Straioto FG, da Silva WJ, Del BelCurry AA. Preload loss and bacterial penetration on different implant-abutment connection systems. *Braz Dent J* 2010;21(2):123–129.
- Broggini N, McManus LM, Hermann JS, Medina R, Schenk RK, Buser D. Peri-implant inflammation defined by the implant-abutment interface. *J Dent Res* 2006;85(5):473–478.
- Hecker DM, Eckert SE. Cyclic loading of implant-supported prostheses: Changes in component fit over time. *J Prosthet Dent* 2003;89(4):346–351.

30. Levine RA, Clem DS, Wilson TG JR, Higginbottom F, Solnit G. Multicenter retrospective analysis of the ITI implant system used for single-tooth replacements: Preliminary results at 6 or more months of loading. *Int J Oral Maxillofac Implants* 1997;12:237–242.
31. 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;9(2):169–178.
32. McGlumphy EA, Mendel DA, Holloway JA. Implant screw mechanics. *Dent Clinics North Am* 1998;42(1):71–89.
33. Khraisat A, Hashimoto A, Nomura S, Miyakawa O. Effect of lateral cyclic loading on abutment screw loosening of an external hexagon implant system. *J Prosthet Dent* 2004;91(4):326–334.
34. Alkan I, Sertgoz A, Ekici B. Influence of occlusal forces on stress distribution preloaded dental implant screws. *J Prosthet Dent* 2004;91(4):319–325.
35. Burguete RL, Johns RB, King T, Patterson EA. Tightening characteristics for screwed joints in osseointegrated dental implants. *J Prosthet Dent* 1994;71(6):592–599.
36. Squier RS, Poster WJ, Taylor TD. Removal torques of conical, tapered implant abutments: The effects of anodization and reduction of surface area. *Int J Oral Maxillofac Implants* 2002;17(1):24–27.
37. Döring K, Eisenmann IE, Stiller M. Functional and esthetic considerations for single-tooth Ankylos implant-crowns: 8 years of clinical performance. *J Oral Implantol* 2004;30(3):198–209.
38. Weigl P. New prosthetic restorative features of Ankylos implant system. *J Oral Implantol* 2004;30(3):178–188.
39. Rack A, Rack T, Stiller M, Riesmeier H, Zabler S, Nelson K. In vitro synchrotron-based radiography of micro-gap formation at the implant-abutment interface of two-piece dental implants. *J Synchrotron Rad* 2010;17(2):289–294.
40. Tsuge T, Hagiwara Y, Matsamura H. Marginal fit and microgaps of implant-abutment interface with internal anti-rotation configuration. *Dent Mater J* 2008;27(1):29–34.
41. Gratton DG, Aquilino SA, Stanford CM. Micromotion and dynamic fatigue properties of the dental implant-abutment interface. *J Prosthet Dent* 2001;85(1):47–52.
42. Bozkaya D, Müftü S. Mechanics of the tapered interference fit in dental implants. *J Biomechanics* 2003;36(11):1649–1658.
43. Dibart S, Warbington M, Su MF, Skobe Z. In vitro evaluation of the implant-abutment bacterial seal: the locking taper system. *Int J Oral Maxillofac Implants* 2005;20(5):732–737.
44. Zambon JJ. *Actinobacillus actinomycetemcomitans* in human periodontal disease. *J Clin Periodontol* 1985;12:1–20.