Impact of Implantoplasty on Strength of the Implant-Abutment Complex

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Purpose: *Implantoplasty, a procedure that is done to smooth contaminated implant surfaces, has been used in the treatment of peri-implantitis. It reduces the implant diameter, which might compromise the implant's strength. This in vitro study was designed to evaluate the effect of implantoplasty on implant strength.* ***Materials and Methods:*** *Thirty-two tapered implants were used; half were 3.75 mm in diameter (narrow) and the other half were 4.7 mm in diameter (wide). All implants were connected to 20-degree angled abutments. The apical half of each implant was embedded in acrylic resin. Eight 3.75-mm- and eight 4.7-mm-diameter implants were randomly assigned to receive implantoplasty. The remaining implants did not receive implantoplasty (control group). Implantoplasty was performed with a series of diamond and polishing burs. The specimens were then loaded 30 degrees off-axis in a universal testing machine until fracture failure occurred. Bending and fracture strength values were recorded and analyzed statistically (α = .05). The fractured surfaces were evaluated under a scanning electron microscope.* ***Results:*** *All narrow implants failed by fracture at the implant platform. The mean bending strength of narrow implants was statistically significantly reduced by implantoplasty (511.4 ± 55.9 N versus 613.9 ± 42.8 N). Implantoplasty did not affect the strength of wide implants; fracture failures occurred at the abutment screw. The fracture mode was ductile and the crack growth was oblique in direction, indicating complex stress distribution and concentration under loading.* ***Conclusion:*** *Within the limits of this study, implantoplasty appeared to weaken the strength of narrower implants. Therefore, this procedure should be performed with caution on narrower, freestanding implants that are subject to greater occlusal force (eg, posterior regions). Validation of these results is needed for different implant systems.* Int J Oral Maxillofac Implants 2013;28:1530–1535. doi: 10.11607/jomi.3227

Key words: *bending strength, ductile fracture, implantoplasty, peri-implantitis, rough surface*

Peri-implantitis is an infectious disease characterized by continuous loss of peri-implant bone.[1,2] Studies have shown that roughened implant surfaces, when contaminated, might accelerate the progression of peri-implantitis.[3] This is because, once exposed to the oral environment, a roughened implant surface is an ideal niche for bacterial plaque to attach and proliferate. If left uncontrolled, the infection can result in further peri-implant bone loss, leading to exposure of more of the implant surface and eventual loss of osseointegration.[1,2]

A number of methods have been introduced to manage peri-implantitis,[4,5] but surgical intervention is preferred because it is more effective in treating the disease.[6] A regenerative or resective approach may be used, based on the configuration of the peri-implant bone defect.[7] The regenerative procedure uses bone grafts and/or barrier membranes to fill the defect and achieve reosseointegration around infected implants.[8] However, this approach does not predictably result in reosseointegration, because there is no effective method to decontaminate rough implant surfaces.[9] The resective procedure, on the other hand, eliminates peri-implant infection by removing unsupported bone around infected implants.[4] Resection is often combined with implantoplasty, a procedure that modifies implant surfaces by removing exposed implant

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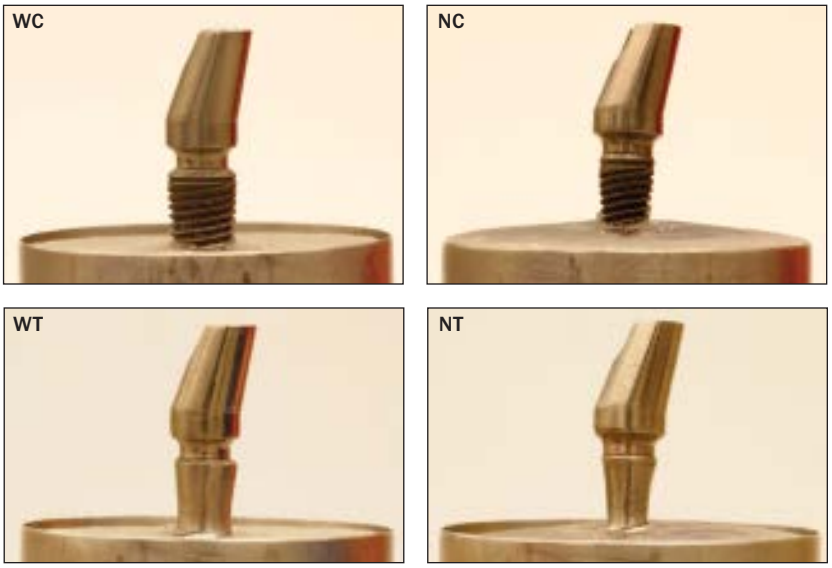

Fig 1 Representative specimens of the four experimental implant-abutment assemblies demonstrating geometry of standard 20-degree angled abutments and the coronal 5 mm of the implant body, which was left exposed to simulate bone loss.

threads and rough surfaces.[10,11] This procedure was reported to favorably reduce pocket depth and maintain marginal bone levels over a 3-year follow-up period.[10] Enhanced access to hygiene practices might have contributed to the observed clinical improvement.

Implantoplasty inevitably reduces the implant diameter and thickness of the implant walls. Coupled with the more unfavorable crown-implant ratio caused by bone loss from peri-implantitis, the thinner implant wall may experience bending under high masticatory forces and thus fracture.[12–16] This type of failure is catastrophic and irreversible, resulting in impaired occlusal function.[17–19] As such, the present study was designed to evaluate the effect of implantoplasty on implant strength. The working hypothesis was that implantoplasty could significantly reduce the bending and fracture strength of dental implants.

MATERIAL AND METHODS

Specimen Preparation

Thirty-two tapered dental implants (TRI-Vent implants, TRI Dental Implants), 16 of which were 3.75 × 10 mm (N) and 16 of which were 4.7 × 10 mm (W), were divided into test (T) and control (C) groups. Implants in the T groups (n = 8 per group; NT and WT) were randomly selected and received implantoplasty, while the remaining implants served as controls (n = 8 per group; NC and WC). All implants had surfaces that had been roughened by blasting with zirconia oxide (60- to 125-μm particles for the crestal area and 150- to 250-μm particles throughout the body and apical area). The implants are of a square thread design with a 0.5-mm smooth collar as the implant platform. The implant and abutment are connected internally by a 1.5-mm-deep, 2.5-mm-wide flat-to-flat hexagonal platform.

With a dental surveyor (AMD Dental Mfg), the implants were aligned perpendicularly in a customized stainless steel jig and fixed in an autopolymerizing clear acrylic resin (Acrylic Self Cure, Henry Schein). Only 5 mm of the implant was embedded in acrylic resin to simulate marginal peri-implant bone loss. After polymerization of the acrylic resin was complete, a standard 6-mm-high, 20-degree angled abutment (Standard-20° TRI-Friction, TRI Dental Implants) was connected to each implant specimen with a ratchet to 35 Ncm (Fig 1).

For the WT and NT groups, implantoplasty was performed by an experienced periodontist (HC). Implant threads that were not covered by acrylic resin were removed with 30- and 15-μm egg-shaped diamond burs (Henry Schein) attached to a handpiece running at 15,000 rpm. Subsequently, the surfaces were polished and smoothed with finishing burs (Arkansas burs and fine silicone polishers, Henry Schein) (Fig 1). The procedure was performed under magnification ×2.5 (Design for Vision) with the aid of a dental chair light. The smoothness of the surface was examined and confirmed.

Fracture and Bending Strength Testing

The laboratory settings for the strength testing are illustrated in Fig 2. Each prepared specimen was secured by a stainless steel jig in a universal testing machine (Model 5565, Instron Corp). The abutment-implant complex was loaded by a stainless steel indenter against an indentation with a size of 0.5 × 0.5 mm on the coronal surface of the abutment. The load was transferred at

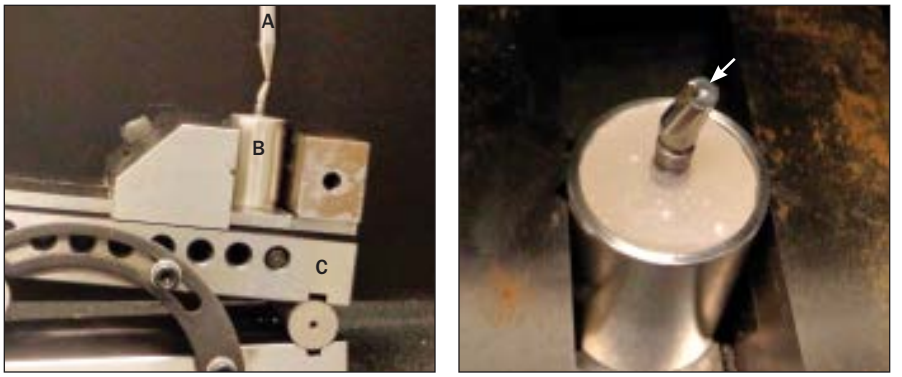

Fig 2 Laboratory settings for fracture strength testing. (*Left*) A = the indenter applying forces at a crosshead speed of 0.5 mm/min; B = the jig containing the implant that was embedded in acrylic resin; a 20-degree angled abutment was attached to the implant; C = the table of the test machine that was positioned at an angle of 10 degrees relative to the floor. (*Right*) An indentation was prepared on the abutment (*white arrow*) to receive the indenter.

Table 1 Mean Bending and Fracture Strengths (in Newtons) of the Three Experimental Groups

	Bending strength		Fracture strength	
Group	Mean	SD	Mean	SD
WT (n = 8)	802.9*†	91.3	430.4*†	26.8
NT (n = 8)	511.4*‡	55.9	321.7*	21.4
NC (n = 8)	613.9†‡	42.8	325.0†	20.7

For bending strength, statistically significant differences were found *between WT and NT, †between WT and NC, and ‡between NT and NC. For fracture strength, statistically significant differences were found *between WT and NT and †between WT and NC.

a 30-degree angle (10-degree tilt of the metal jig plus 20-degree tilt of the angled abutment) to the long axis of the implant at a crosshead speed of 0.5 mm/min until a fracture failure of the implant-abutment complex occurred.[20] The strength of each specimen was determined on the load-versus-chart-speed curve calculated by a software program (Merlin Software, Instron Corp); the highest peak was chosen to characterize bending strength. Fracture strength was indicated by crack initiation for each specimen, as determined by a sharp decrease of loading in the curve and confirmed by an audible sound.

Scanning Electron Microscopy Examination

Each fracture surface of the implant/abutment complex specimens was cleaned under a pressure-vaporized steam cleaner (Steaman II Bar Instruments) for 1 minute. The specimens were mounted on a metal plate and viewed under a scanning electron microscope (SEM) (AMRAY Model 1910 field, SEM-Tech Solutions) to determine the mode of fracture failure and the initiation and propagation of the crack. The machine was operated at 5 kV, and digital images of the investigated fracture surfaces were collected with digital imaging software (XSTREM, SEM-Tech Solutions).

Statistical Analyses

The values for bending and fracture strength of each specimen were calculated in Newtons and compared between the test and control groups for both diameters of implants using one-way analysis of variance. A post hoc analysis was conducted with the Tukey test (α was set at the level of .05). All statistical analyses were performed with computer software (EXCEL 2010, Microsoft).

RESULTS

Implantoplasty reduced the thickness of the implant lateral walls. The fracture locations differed between N and W implants. Fracture failures occurred on the bodies of N implants, whereas they occurred at the abutment screws of W implants. There were no statistically significant differences in the mean fracture strength (P = .70) between NT and NC; however, the mean bending strength values were statistically significantly different between the two groups (P < .001) (Table 1, Fig 3). The mean bending strength was reduced by 17% (from 613.9 to 511.4 N) after implantoplasty. Two fracture lines were observed on NT implant bodies, whereas only one was found on an NC implant body (Fig 4).

WT implants failed at the abutment screws, indicating that implantoplasty had no impact on the strength

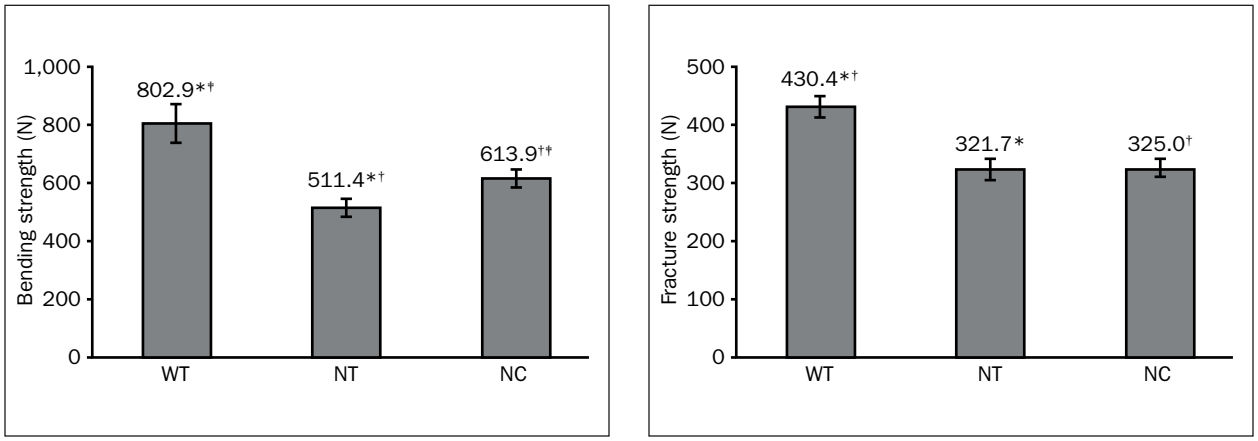

Fig 3 Illustration of the mean values for (*top*) bending strength and (*bottom*) fracture strength for the three experimental groups (strength values of WC implants were not measured because these implants remained intact). The groups marked with same symbols are significantly different (Tukey test, $\alpha = .05$).

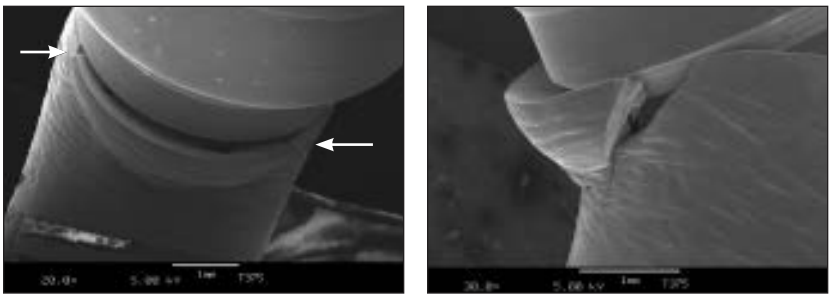

Fig 4 SEM images of the plastic deformation and fracture failure of an NT implant-abutment complex specimen. (*Left*) Two fracture lines were found on the implant (*white arrows*). (*Right*) Oblique direction of fracture path extending from the platform along the body of implant.

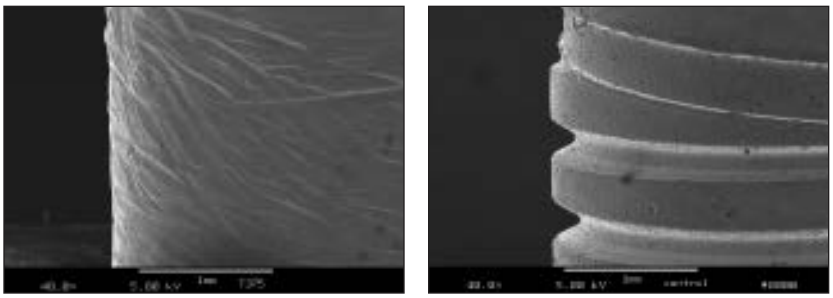

Fig 5 SEM images of the implant surfaces of (*left*) control and (*right*) test groups. Note the surface modified by implantoplasty revealing absence of the threads and multiple grooves and ridges created by burs.

of the implant bodies. The implant bodies were intact, without signs of plastic deformation. Thus, WC implants were not subjected to loading tests. The mean bending and fracture strength values of WT implants were statistically significantly higher than those of NT and NC groups ($P < .001$) (Table 1, Fig 3).

SEM Findings

The implants modified by rotary instruments presented relatively smooth and uniform surfaces, with the threads having been removed along the body. However, these surfaces appeared irregular, with multiple grooves and ridges characterized by tracks of bur marks (Fig 5). On NC and NT implants, the fractures were oblique in direction, with gross plastic deformation of the body and platform of the implant (Fig 6). Cracks developed at the implant platform and advanced apically along the implant body. The mode of fracture was ductile, characterized by rough and dull surfaces consisting of numerous dimples and microvoids formed along the path of crack propagation.

On WT implants, the fracture surfaces of the abutment screws revealed the entire course of initiation and propagation and the end point of fracture. The crack occurred at the site of tensile stress accumulation, opposite to the site of loading. The dominant mode of fracture was ductile with slow crack growth; however, the end stage of fracture was rapid, as indicated by a mirror image of a shiny surface (Fig 7).

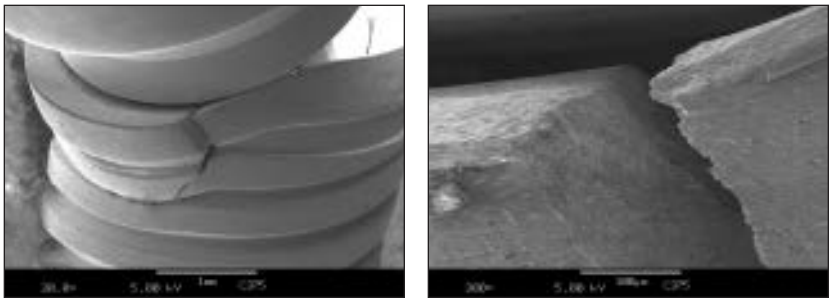

Fig 6 SEM images of the plastic deformation and fracture failure of an NC implant-abutment assembly. (*Left*) Oblique pattern of fracture failure, limited to one area of the implant. (*Right*) The rough fracture surface demonstrates the ductile mode of failure.

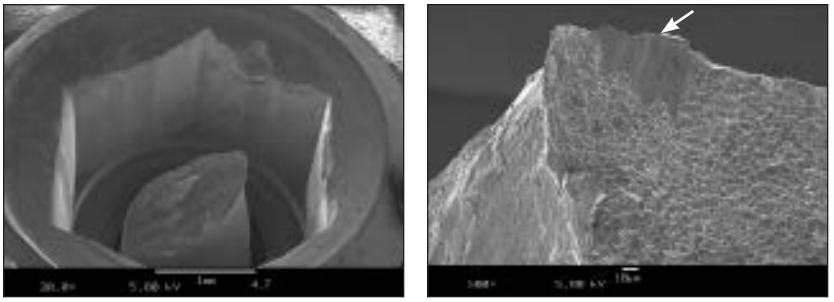

Fig 7 SEM images of fracture surface of the abutment screw from the WT group. (*Left*) Oblique orientation of fracture path extending from the side opposite to the bending. (*Right*) Fracture surface demonstrating a slow mode of ductile fracture consisting of dimples and microvoids mixed with end stage of rapid fracture, as indicated by a mirror image of the shiny surface (*white arrow*).

DISCUSSION

Horizontal bony defects caused by peri-implantitis are generally managed by bone resective surgeries in combination with implantoplasty.[7,10,11] The clinical efficacy of implantoplasty has been evaluated and implantoplasty has been shown to increase the implant survival rate, reduce pocket depths and signs of inflammation, and maintain crestal bone levels.[10,11] This is the first study to investigate the risk of mechanical failure in the implant-abutment complex following implantoplasty.

Implant strength is derived from the thickness of the implant wall.[15,16] The wall of the N implants used in the present study was almost one-half the width (0.625 mm) of the wall of the W implants (1.1 mm). Therefore, under static loading, the W implants had significantly higher bending and fracture strength than the N implants. Additionally, according to the manufacturer, the thread depth of the implant system tested at its coronal portion is 0.2 mm. After threads are removed and additional finishing and polishing procedures are accomplished, the wall thickness of the N implants was reduced to approximately 0.425 mm; in other words, it lost 32% of its original thickness. As a result, the bending strength significantly decreased, by 102.5 N (from 613.9 to 511.4 N), or by 16.7% of the original strength. On the other hand, the strength of the W implants was not affected by implantoplasty because the fractures occurred at the abutment screws. Therefore, a certain implant wall thickness must be present to resist bending forces. The current results might not be able to predict the performances of other implant systems, because the implant strength as a function of wall thickness reduction varies with different implant geometries and diameters.[19,21]

The implant diameter should be considered carefully during treatment planning. A narrower-diameter implant, defined by Degidi et al[22] and Sohrabi et al[23] as having a diameter of 3.0 mm and < 3.5 mm, respectively, may not be suitable to replace posterior teeth, which are subject to higher occlusal forces, although short-term performance of narrow implants seems comparable.[22,23] This is especially true if implantoplasty must be performed on those implants, because the procedure further decreases the implant strength. In this study, each NT implant had two fracture lines, whereas the NC implant had only one fracture with a slower growth of the crack. This pattern of failure is related to the degree of plastic deformation from reduction of the wall thickness[12] and to the creation of microscopic irregularities after implantoplasty. Therefore, for atrophic ridges in the posterior region, a ridge augmentation procedure, followed by placement of wider implants, may be a preferred option.

The mode of fracture was ductile, with plastic deformation of the implants and abutment screws, as suggested by the SEM examinations. The fractured surfaces were rough, consisting of dimples or microvoids of relatively high surface energy. Tensile stresses developing within the implant-abutment complex under loading can lead to fractures of implants or screws.[17–19] The implants failed at the platform on the

bending side, with the fracture growing slowly in the apical direction along the implant body with bending of the abutment screw.

Meanwhile, the W implants did not experience plastic deformation under loading; instead, fractures were limited within the abutment screws. The crack developed on the opposite side of the bending and grew in an oblique direction, with stress localization of bending perpendicular to the axis of principal tension. The fracture continued to grow until it released the energy through the newly created surfaces of the complete fracture. The mode of fracture was slow; however, the end point of catastrophic fracture failure was rapid, leaving a mirror image of a shiny surface at the tip of breakage. This initial slow mode of bending and crack growth can be noted intraorally with changes in occlusal contacts.[24] Thus, patients who have received implantoplasty should be monitored regularly to evaluate occlusal contacts and identify early signs of mechanical failure of the implant-abutment complex.

CONCLUSIONS

Within the limits of this study, narrower (3.75-mm) internal-connection implants were more prone to failure by fracture after implantoplasty. The implant fractured when the thickness of the lateral walls was insufficient to resist bending forces. Care should be taken when performing implantoplasty to avoid nonuniform reduction of the wall thickness along the length of an implant. Wider implants are therefore preferred in posterior areas to prevent possible catastrophic implant fracture when implantoplasty is required. The clinical relevance of this failure mechanism in the implant-abutment complex should be further tested with experimental conditions similar to the intraoral environment, for example, application of dynamic loading.

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REFERENCES

1. Zitzmann NU, Berglundh T. Definition and prevalence of peri-implant diseases. J Clin Periodontol 2008;35:286–291.
2. Heitz-Mayfield LJ. Peri-implant diseases: Diagnosis and risk indicators. J Clin Periodontol 2008;35:292–304.
3. Renvert S, Polyzois I, Claffey N. How do implant surface characteristics influence peri-implant disease? J Clin Periodontol 2011;38 (suppl 11):214–222.
4. Aljateeli M, Fu JH, Wang HL. Managing peri-implant bone loss: Current understanding. Clin Implant Dent Relat Res 2012;14 (suppl 1):e109–118.
5. Esposito M, Grusovin MG, Coulthard P, Worthington HV. The efficacy of interventions to treat peri-implantitis: A Cochrane systematic review of randomised controlled clinical trials. Eur J Oral Implantol 2008;1:111–125.
6. Renvert S, Roos-Jansaker AM, Claffey N. Non-surgical treatment of peri-implant mucositis and peri-implantitis: A literature review. J Clin Periodontol 2008;35:305–315.
7. Schwarz F, Sahm N, Schwarz K, Becker J. Impact of defect configuration on the clinical outcome following surgical regenerative therapy of peri-implantitis. J Clin Periodontol 2010;37:449–455.
8. Claffey N, Clarke E, Polyzois I, Renvert S. Surgical treatment of peri-implantitis. J Clin Periodontol 2008;35:316–332.
9. Renvert S, Polyzois I, Maguire R. Re-osseointegration on previously contaminated surfaces: A systematic review. Clin Oral Implants Res 2009;20(suppl 4):216–227.
10. Romeo E, Lops D, Chiapasco M, Ghisolfi M, Vogel G. Therapy of peri-implantitis with resective surgery. A 3-year clinical trial on rough screw-shaped oral implants. Part II: Radiographic outcome. Clin Oral Implants Res 2007;18:179–187.
11. Romeo E, Ghisolfi M, Murgolo N, Chiapasco M, Lops D, Vogel G. Therapy of peri-implantitis with resective surgery. A 3-year clinical trial on rough screw-shaped oral implants. Part I: Clinical outcome. Clin Oral Implants Res 2005;16:9–18.
12. Gealh WC, Mazzo V, Barbi F, Camarini ET. Osseointegrated implant fracture: Causes and treatment. J Oral Implantol 2011;37:499–503.
13. Piattelli A, Piattelli M, Scarano A, Montesani L. Light and scanning electron microscopic report of four fractured implants. Int J Oral Maxillofac Implants 1998;13:561–564.
14. Rangert B, Krogh PH, Langer B, Van Roekel N. Bending overload and implant fracture: A retrospective clinical analysis. Int J Oral Maxillofac Implants 1995;10:326–334.
15. Shemtov-Yona K, Rittel D, Levin L, Machtei EE. Effect of dental implant diameter on fatigue performance. Part I: Mechanical behavior. Clin Implant Dent Relat Res 2012 Jul 10. [Epub ahead of print]
16. Shemtov-Yona K, Rittel D, Machtei EE, Levin L. Effect of dental implant diameter on fatigue performance. Part II: Failure analysis. Clin Implant Dent Relat Res 2012 Jul 10. [Epub ahead of print]
17. Seetoh YL, Tan KB, Chua EK, Quek HC, Nicholls JI. Load fatigue performance of conical implant-abutment connections. Int J Oral Maxillofac Implants 2011;26:797–806.
18. Lee FK, Tan KB, Nicholls JI. Critical bending moment of four implant-abutment interface designs. Int J Oral Maxillofac Implants 2010;25: 744–751.
19. Dittmer S, Dittmer MP, Kohorst P, Jendras M, Borchers L, Stiesch M. Effect of implant-abutment connection design on load bearing capacity and failure mode of implants. J Prosthodont 2011;20:510–516.
20. Al-Omari WM, Shadid R, Abu-Naba'a L, El Masoud B. Porcelain fracture resistance of screw-retained, cement-retained, and screw-cement-retained implant-supported metal ceramic posterior crowns. J Prosthodont 2010;19:263–273.
21. Almeida EO, Freitas AC Jr, Bonfante EA, Rocha EP, Silva NR, Coelho PG. Effect of microthread presence and restoration design (screw versus cemented) in dental implant reliability and failure modes. Clin Oral Implants Res 2013;24:191–196.
22. Degidi M, Nardi D, Piattelli A. Immediate restoration of small-diameter implants in cases of partial posterior edentulism: A 4-year case series. J Periodontol 2009;80:1006–1012.
23. Sohrabi K, Mushantat A, Esfandiari S, Feine J. How successful are small-diameter implants? A literature review. Clin Oral Implants Res 2012;23:515–525.
24. Hsu YT, Fu JH, Al-Hezaimi K, Wang HL. Biomechanical implant treatment complications: A systematic review of clinical studies of implants with at least 1 year of functional loading. Int J Oral Maxillofac Implants 2012;27:894–904.