Bone Microstrain Values of 1-Piece and 2-Piece Implants Subjected to Mechanical Loading

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Purpose: *The purpose of this study was to measure and compare the strain levels in peri-implant bone as generated by 1-piece (1P) and 2-piece (2P) implant systems.*

Materials and Methods: *The implants (1P and 2P) were placed into bovine bone according to the manufacturer's protocol. Four linear strain gauges were placed around each implant neck and apex. Each model was loaded in static loading by a material testing machine in ascending forces ranging from 20 to 120 N. Microstrains (με) generated in the surrounding bone were measured by a strain gauge and recorded.*

Results: *Recorded microstrains were significantly higher for 1P implants than for 2P implants. Average recorded microstrain values were significantly lower in the neck (71.6 and 17.3 μs) compared with the apical (132 and 60 μs) regions of 1P and 2P implants, respectively ($P < 0.0001$).*

Conclusions: *Within the limitations of this study, highest microstrains were generated in apical regions regardless of implant design, but the 2P implant appeared to provide a stress-damping effect in both the cervical and apical regions compared with the 1P implant. (Implant Dent 2013;0:1–5)*

Key Words: bone, microstrain 1-piece implant

Frost[1] postulated that there is a regulatory mechanism that adapts bone mass according to the intensity of microstrains (με) generated inside the osseous tissue at the bone-implant interface. For example, 200 με is less associated with bone atrophy from under stimulation, 200 to 2500 με is equated with balanced bone remodeling (steady state), 2500 to 4000 με may trigger bone growth (hypertrophy), and 4000 με or greater can theoretically lead to bone resorption (eg, pathological overload).[1] Natural teeth and dental implants distribute forces differently in the surrounding bone.[2] The main biomechanical difference is that dental implants lack a stress-reducing element, such as the periodontal ligament, which exists around natural teeth to absorb and distribute occlusal forces to the supporting bone.[3] In addition, natural teeth contain mechanoreceptors that sense the mechanical load and provide important feedback to the patient regarding potential dangers to the dentition when chewing hard substances.[4,5] From a biomechanical perspective, the physiological and anatomical differences between natural teeth and implants greatly impact force distribution and microstrains within the supporting bone.[6–10]

Dental implants must fulfill certain criteria: biocompatibility, adequate mechanical strength, optimum soft and hard tissue integration, and transmission of functional forces to bone within physiological limits.[11,12] One of the critical elements influencing the long-term uncompromised functioning of a dental implant is its design.[13–15] Implant design is characterized by its composition material, overall shape, thread design, prosthetic platform, abutment connection, surface topography, and physiochemical composition, all of which determine its biomechanical behavior.[16–20]

The implant-abutment connection affects stress distribution in bone.[21,22] Baggi et al[23] investigated the influence of implant diameter and length on stress distribution to calculate the overload risk in crestal bone around the implant neck. They found that stress values and concentration areas decreased in cortical bone when implant diameter increased; whereas more effective stress distributions for cancellous bone were experienced with increasing implant length.

Stress distribution in bone may also be affected by different abutment

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connections, such as internal and external designs.[18,24–26] Differences in stress distribution patterns between implants with external or internal hex connections were compared using *in vitro* models.[23] External hex implants showed an increase in microstrains at the cervical area under horizontal load, whereas in internal hex implants, microstrains were located in the implant's apical region.[22] These findings suggested that internal hex implant designs widely distributed forces down to their apical regions compared with the crestal bone concentrations of external hex implants.

In contrast to 2-piece (2P) implant designs, 1-piece (1P) implant systems consist of the implant and abutment manufactured together from a single section of titanium bar stock. This completely eliminates the implant-abutment connection. An FEA study was conducted to investigate the effect of 3 different abutment types on the stress distribution in bone when subjected to inclined loads.[26] The study found that 1P implants transferred loads evenly throughout the implant system and into the bone. However, the maximum Von Mises stress generated in bone with the 1P implant was always higher than the stresses generated with the 2P internal hex implant, regardless of load angle inclination. In the case of the 2P internal hex implant, the tapered frictional joint connection between the abutment and the implant neck reduced the effect of bending caused by the horizontal component of inclined load.

Another FEA study[19] analyzed the force transmission and distribution characteristics of 1P and 2P implants and found that 2P implants experienced higher mechanical stress under oblique loading. Other FEA studies found similar force distribution patterns in different implant designs.[27,28] Several variables can adversely affect the predictive accuracy of FEA models, such as model geometry, material properties, applied boundary conditions, and the bone-implant interface.[29] Because these variables may be different in each study, FEA results may be inconsistent from one study to the next. Other techniques for analyzing microstrains in peri-implant bone include the use of strain gauges, photoelastic models, or a combination of these methods. In contrast to the FEA method, strain gauge results are measured clinically rather than digitally. Strain gauges are also generally bonded directly to, or in, the vicinity of the implant surface,[30,31] and the implants are generally embedded in a photoelastic model rather than in bone. However, no studies, to date, have bonded strain gauges to the bone surface for the comparison of 1P and 2P implants.[16,17,32,33]

This article reports on a study that was conducted to compare the microstrains generated in peri-implant bone by 1P and 2P implant systems.

MATERIALS AND METHODS

Osteotomies were sequentially prepared in a bovine rib using a reduction contra-angle (Nouvag AG, Goldach, Switzerland) and sequential cutting with internally irrigated drills. A 1P implant (Zimmer One-Piece Implant; Zimmer Dental, Inc., Carlsbad, CA) and 2P implant (Tapered Screw-Vent; Zimmer Dental, Inc.) were placed into the osteotomies according to the manufacturer's protocols. A screw-retained abutment (Hex-Lock Contour Abutment; Zimmer Dental, Inc.) was attached to the 2P implant and tightened to 20 Ncm with a calibrated torque wrench.

The distance from the implant apexes to bone cortex was about 2 mm in both samples (Fig. 1). Two linear strain gauges, 350 Ω nominal distance, were placed around each implant on the bone surface 1 mm from the cervical part (C2A-13-062LW-350; Vishay Measurements Group, Inc., Holon, Israel) and 1 mm from its apical part (C2A-06-125LW-350; Vishay Measurements Group, Inc.) (Fig. 2). The measurement direction was parallel to the long axis of the implant on the tension side. The strain gauges were covered with AE 10 EPOXY and cemented to the bone (M-BOND 200; Vishay Measurements Group, Inc.). The strain gauges were connected to a strain indicator (Vishay 2100; Vishay Measurement Group, Inc.). Each test specimen was mounted at a 30-degree angle in a mechanical testing machine (Instron 4502; High Wycombe, Buckinghamshire, United Kingdom). Loading at a 30-degree angle was achieved by mounting the implant in angulations and vertical loading (Fig. 3). Each sample was tested in 5 cycles with 4 loading measurements between 20 and 120 N. After every cycle, the test setup with the

Fig. 1. X-ray of the 1P implant after inserted into the bovine bone. The implant is angulated to create 30 degrees in loading.

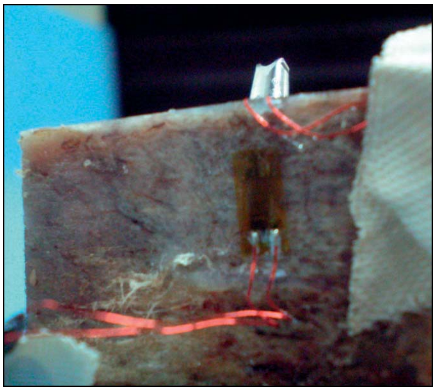

Fig. 2. The strain gauges connected directly to the bone surface in the apical and cervical parts of the implants.

Fig. 3. The Instron loading machine creates vertical pressure on the abutment connected to the implant, resembling nonaxial loading.

Table 1. Comparison Between 1P and 2P Implants

	Implant Design	N	Mean με	Min	Max
Neck	1P	18,352	132	1	305
	2P	17,476	59.3876	1	165
	P		<0.0001		
Apical	1P	18,352	71.5786	1	777
	2P	17,476	17.3456	1	48
	P		<0.0001		

Intergroup comparisons of cervical and apical microstrain (με) values at 2 levels of 1P implants: strains around 1P implants significantly higher.

Table 2. Comparisons of Strains Around Neck and Apex of Implants

Implant Design		N	Mean μs	SD	Min	Max
1P	Neck	18,352	132	78.2809	1	305
	Apical	18,352	71.5786	137.9	1	777
	P		<0.0001	<0.0001		
2P	Neck	17,476	59.3876	24.7185	1	165
	Apical	17,476	17.3456	12.9147	1	48
	P		<0.0001	<0.0001		

Intragroup comparisons of cervical and apical microstrain (με) values at 2 levels of 1P and 2P implants: strains around cervical part ("neck") significantly higher.

implant was removed from the machine and released for a few seconds and then reconnected again at the same position.

Statistical Analysis

Four *t* tests were performed to assess 2 intergroup and 2 intragroup comparisons:

- Intergroup comparison of neck values between 1P and 2P implants.
- Intergroup comparison of apical values between 1P and 2P implants.
- Intragroup comparison of neck and apical values of the 1P implant.
- Intragroup comparison of neck and apical values of the 2P implant.

Before *t* tests were considered, a Folded *F* test was performed to test the assumption of equal variances. If the Folded *F* test was statistically significant ($P < 0.05$), then a Satterthwaite *t* test was calculated.

RESULTS

The microstrains measured around 1P implants were significantly higher than those measured around 2P implants (Table 1). The higher values were recorded at both the cervical and apical ends of the implants. The average microstrain at the apex was 71.6 με in the 1P implant and 17.3 με in the 2P implant. At the cervical end, the average microstrain was 132 με in the 1P implant and approximately 60 με in the 2P implant.

In both 1P and 2P implants, microstrains measured around the cervical end ("neck") were significantly higher than those at the apical end ("apex") (Table 2). In 1P implants, the average microstrain was 71.6 με at the apical end and 132 με at the neck. In 2P implants, the average microstrain was 17.34 με at the apical part and 59.4 με at the neck.

DISCUSSION

In this study, microstrain levels in the peri-implant bone of 1P and 2P implant systems were measured and compared. Abutment type (removable/2P implants or nonremovable/1P implants) significantly influenced stress distributions in bone because of differences in load transfer mechanisms and the size of the implant-abutment contact area. Thus, different implant-abutment configurations may positively or adversely affect stress levels in peri-implant bone, which can trigger different bone remodeling responses.[1] In the 1P implants, load was transferred more evenly in both the implant body and surrounding bone than in the 2P implants. In another study, Dittmer et al[21] evaluated the abutments from 5 different implant systems and found that the type of implant-abutment connection significantly influenced the load-bearing capacity of implants. In contrast to indirect stress measurements generated in FEA[19,23,24,26–28,34] and photoelastic[31,35] studies, the present study model measured peri-implant stresses directly on the bone.

In general, microstrains measured in the cervical region of the implant were significantly higher than those measured in the apical region of the implant, regardless of the implant design. When the 2 implant designs were compared, however, cervical and apical microstrains measured around the 1P implants were significantly higher than those measured around the 2P implants. The results correlate with an FEA analysis conducted by Chun et al,[26] which found the stress differences between implants with internal and external connections, in the 1P implant designs. The internal hex connection reduced the bending effect by sliding the tapered joints between the implant and the abutment and thus reduced Von Mises stresses.[26]

Long-term clinical evaluation is needed to assess if the higher microstrains measured around 1P implants in this mechanical study would be capable of inducing higher bone resorption at the clinical level. Of the few short-term prospective studies that have evaluated bone loss around 1P implants, most of the implants were reported to have some marginal bone loss of 1 to 2 mm.[36–39] Taking into consideration the fact that 1P implants have no implant-abutment microgap, a question arises as to whether the observed bone loss was attributable to implant design, surgical technique, clinician learning curve,[29] or some other factors. An important consideration is the fact that 1P implants are always immediately loaded to some degree regardless of the planned prosthetic scheme. Bone loss may thus be attributable to premature implant loading when the transmucosal post is subjected to lip, tongue, and cheek pressures and inadvertent contact with food boluses during chewing, even when the implant is not intentionally placed into function.

The use of bovine bone to simulate the clinical condition may be more accurate than other studies that use resin (photoelastic models) or computerized models (FEA) to evaluate the stress distribution. A major limitation of this study, however, was the small sample size of implants examined. Prospective clinical research is needed to determine the long-term effects of load distribution around implants and abutments of various designs.

CONCLUSIONS

Within the limitations of this study, 1P implants exhibited numerically higher peri-implant microstrains in both the cervical and apical regions than 2P implants in the same length and diameter, but the effect that this difference in magnitude might have on peri-implant bone maintenance could not be evaluated in the present model.

DISCLOSURES

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

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