The Effect of Implant Shape and Screw Pitch on Microdamage in Mandibular Bone

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ABSTRACT

Purpose: The aim of this study was to investigate the effect of implant shape and screw pitch on microdamage in bone during insertion of dental implants.

Materials and Methods: Thirty custom-made implants (length, 10 mm; diameters, 4.1 mm; cylindrical, tapered, and taper-cylindrical shapes; screw pitches, 1.25 and 0.8 mm; classified as 1.25C, 0.8C, 1.25T, 0.8T, 1.25TC, 0.8TC) were placed with a surgical device in the mandibles of eight goats. Two implant sites were prepared in the edentulous area on each side of the mandible. Implants were placed in a randomized order. Immediately after placement of the implants, the bone blocks with the implants were collected, bulk stained with basic fuchsin, embedded in methyl methacrylate, and sectioned. Histomorphometric quantification of the microcrack length (Cr.Le, μm); microcrack surface density (Cr.Le/B.Ar, $\mu m/mm^2$), and damaged bone area fraction (DB.Ar/B.Ar, %) were measured.

Results: The Cr.Le, Cr.Le/B.Ar, and DB.Ar/B.Ar values of 0.8TC group were 80.96 ± 17.55, 478.75 ± 51.85, and 4.40 ± 0.36, respectively. All these parameters of microdamage induced by 0.8TC were significantly lower than those induced by other five types of implants ($p < .05$).

Conclusion: Taper-cylindrical implants with 0.8 mm screw pitch caused the least microdamage to the bone in comparison with the other five types of implants during placement of implants.

KEY WORDS: dental implant, implant shape, mandibular bone, microdamage, screw pitch

INTRODUCTION

Microdamage can be generated by the insertion of an implant or fatigue loading.[1–11] It has been suggested that microdamage induces bone remodeling.[3,4,8,12] The process of normal remodeling is thought to repair microdamage. A stable equilibrium is characterized by the same rate of repair and damage.[13] Microdamage is the result of excessive accumulation of stress in bone. If the stresses arising from compression of circumferential bone are high enough to produce microdamage that cannot be repaired by remodeling during implant insertion, they may contribute to local ischemia, bone necrosis, and bone resorption.[10,14,15] It has been noted in dental implantology that there is a critical period between the phases of primary and secondary stability, in which insufficient secondary stability is produced by new bone formation, and primary stability has been reduced as a result of bone resorption. The limited stability in this phase is referred to as a stability dip. During this period, implants are at particular risk of loosening, which is why extensive microdamage should be regarded as a risk factor impairing the implant stability.[16,17]

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Early implants to be documented as success were manufactured from noble or base metals designed in either basket or pin shapes that tried to recreate natural roots of teeth, which then could be utilized to support fixed prostheses. Failures were also reported and believed to be resulted, in part, from poor biomechanics, especially poor implant stability.[18,19] Limited success and biomechanical failures of these implants incited dentists to design new implants. It was recognized that subtle changes made in shape, length, and width of endosseous implants could affect success rates,[20] and implant manufacturers started to provide various implants in designs. The shape and size of implants have been adapted to fit contemporary surgical protocols and prosthetic designs. Since the mid-1990s, the solid-screw implant has become the main implant type, among which cylindrical and tapered are the most common designs of the implant shape.[21] Most recently, the system of various screw-type implants has been supplemented with a new kind of tapered-cylindrical implants, which combines tapered implants and cylindrical implants, developed to be used in postextractive sites.[22–25] To date, only two studies report the influence of implant shape on microdamage. Bartold observed that microcarcks and cross hatch were higher for cylindrical implants, which was opposite to Lee's conclusion.[2,7] No research has involved tapered-cylindrical implants. It has been shown that the maximum effective stress reduced as the screw pitch decreased gradually.[26] However, no study has been reported to detect the influence of screw pitch on microdamage.

In the light of above, we hypothesized that both shape and screw pitch of dental implants will be correlated with the presence of microdamage to bone surface during implant insertion. In this study, cylindrical, tapered, and cylindrical-tapered implants with two different screw pitches are custom made to investigate the effect of implant shape and screw pitch on microdamage in mandibular bone.

Figure 1 Six types of custom-made implants.

MATERIAL AND METHODS

Implant Design

Implants made from titanium alloy Ti–6Al–4V (ASTM grade 5) resembling the solid screw implant of the International Team for Implantology (ITI) Dental Implant System (Institute Straumann AG, Waldenburg, Switzerland) were used (Figure 1). The implants were designed with three different shapes: cylindrical, tapered, and taper-cylindrical implants. There were two different screw pitches for each kind of shape. Each implant was created with a neck that widened from the core diameter in a trumpet shape up to 4.8 mm diameter in the shoulder and an octagon holder connecting the adapter. The experimental implants were classified into six experimental groups according to shape and screw pitch (Table 1, Figure 1). One control group for cylindrical implants and another control group for tapered and taper-cylindrical implants were created. In each control groups, five sham operation procedures were carried out. In the control group for tapered and taper-cylindrical implants, tapered effect profile drills were used.

TABLE 1 Design Parameters of Six Types of Custom-Made Implants

Group	Implant Length (mm)	Diameter (mm)	Screw Pitch (mm)	Implant Shape	*n*
1.25C	10	4.1	1.25	Cylindrical	5
0.8C	10	4.1	0.8	Cylindrical	5
1.25T	10	4.1	1.25	Tapered	5
0.8T	10	4.1	0.8	Tapered	5
1.25TC	10	4.1	1.25	Taper-Cylindrical	5
0.8TC	10	4.1	0.8	Taper-Cylindrical	5

Drilling and Implant Insertion

Mandibles from 10 freshly slaughtered goats (20–30 kg) were used. The alveolar bone between mandibular canine and first premolar is chosen for implantation. The average buccal-lingual width of mandibular ridge in this area is 8.30 mm. The bone quality was classifed as class 3 according to the classification of Lekholm & Zarb.[27] After buccal and lingual muco-periosteal flaps were elevated, two sites were prepared in right or left sides of the mandibles of all goats, and implants were placed in a randomized order. Procedures were conducted according to the standard protocols as recommended by ITI. Round bur was used to mark the implantation sites. After that, the implant beds were prepared by Straumann 2.2 mm Pilot drill 1 (Institute Straumann AG, Basel, Switzerland), Straumann 2.8 mm Pilot drill 2 (Institute Straumann AG), and Straumann 3.5 mm Twist drill PRO (Institute Straumann AG). Straumann Tapered Effect profile drills (Institute Straumann AG) were used for tapered or tapered-cylindrical implants. Taps were not used for all implants. All implants were inserted to a maximum torque of 55 N cm with handpiece by the aid of MD 20 Dual Motor System (Nouvag, Goldach, Switzerland). In control groups, implant beds were prepared only by drilling, and no further procedures were conducted.

Specimen Preparation

Each mandible was separated into the left and the right side by saw following implant insertion. The orientation of the implants can be easily obtained by the presence of the octagon holder. Each side was then sectioned to get two blocks. Each block contained the implant and about 5 mm of surrounding bone mesially and distally. Specimens were then rinsed in running water, fixed with 80% ethanol, dehydrated in a graded ethanol series and en bloc stained with 1% basic fuchsin, and embedded in methyl methacrylate. Basic fuchsin staining identified the following morphological features in the stained tissue: microcracks, cross-hatch, and diffuse staining, collectively described as microdamage.[28]

Each sample was cut along the long axis of the implant buccallingually by using an SP 1600 diamond saw microtome (Leica Instruments, Nussloch, Germany). Two sections of 200 um in thickness were obtained from each sample. Sections were then grounded to 70 um in thickness.

Histological Examination

Microdamage with the bone adjacent to the implant surface was quantified using a semi-automated digitized histomorphometric method. Sections were visualized under green fluorescent light using a Leica DM4000 (Leica, Glattbrugg, Switzerland) microscope at ×10 objective and the images were captured by using a Leica camera (Leica) mounted on a Leica DM4000 microscope. Data of the image were analyzed by Bioquant Osteo II V.10.2 software (Bioquant, Nashville, TN, USA). Digital pictures of each implant screw pattern were taken.

The following quantitative microdamage data were calculated: mean microcrack length (Cr.Le, μm), microcrack surface density (Cr.Le/B.Ar = mean crack length/bone area, $\mu m/mm^2$), and damaged bone area fraction (DB.Ar/B.Ar = microdamage area/bone area, %).[28]

Statistical Analysis

The statistics were analyzed by SAS 8.02 (SAS Institute, Cary, NC, USA). Wilcoxon tests were performed to investigate the effects of shape and screw pitch of dental implants on microdamage in bone during placement. The difference was statistically significant when $p = .05$ or less. Data were expressed as mean ± standard deviation.

RESULTS

On the sham operation sites of both control groups, no evidence of any type of microdamage was discovered adjacent to the holes.

In six experimental groups, microcrack, cross-hatch microdamage, and diffuse microdamage were detected (Figure 2).

Microcrack Length

A column chart illustrating the microcrack lengths of the six groups is presented in Figure 3.

Among the groups with 1.25-mm pitch, the mean values were 150.99 ± 22.98 for the 1.25C implant, 147.46 ± 33.38 for the 1.25T implant, and 93.69 ± 19.03 for the 1.25TC implant. The values of the 1.25TC implant were significantly lower than that of the 1.25T implant or the 1.25C implant ($p < .05$). No statistical significance was found between the 1.25T implant and 1.25C implant ($p = .3295$).

Among the groups with 0.8-mm pitch, the mean values were 146.13 ± 33.38 for the 0.8C implant,

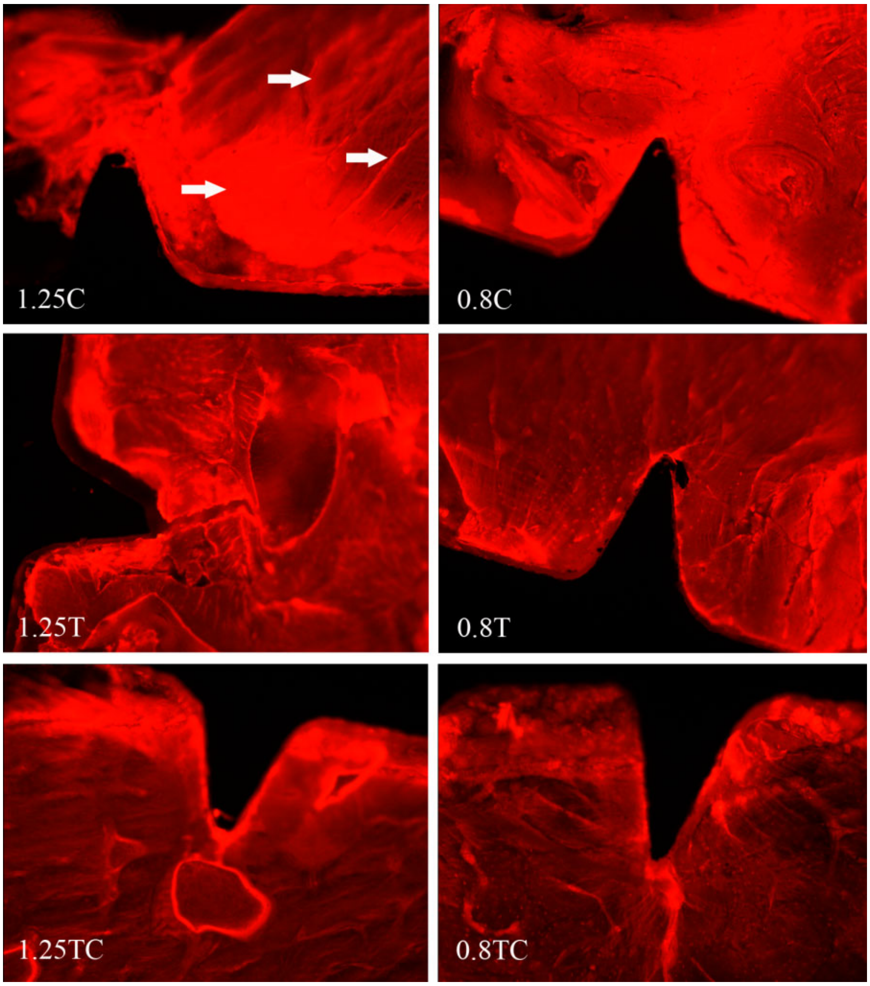

Figure 2 Fluorescent image of six types of implants at ×10 objective (from the left to the right: the arrows identify diffuse damage, cross-hatch damage, and microcrack).

119.41 ± 24.32 for the 0.8T implant, and 80.96 ± 17.55 for the 0.8TC implant. The values of the 0.8TC implant were significantly lower than that of the 0.8T implant or 0.8C implant ($p < .05$). The values of the 0.8T implant were significantly lower than that of the 0.8C implant ($p < .05$).

Between the groups with same implant shape, the values of the 0.8T and 0.8TC implant were significantly lower than the values of the 1.25T and 1.25TC implant, respectively. The values of the 0.8C implant were lower than the values of the 1.25C, but there was no statistical significance between these two groups ($p = .1339$).

Microcrack Surface Density

A column chart illustrating the microcrack surface density of the six groups is presented in Figure 4.

Among the groups with 1.25-mm pitch, the mean values were 1216.34 ± 100.37 for the 1.25C implant, 812.37 ± 46.38 for the 1.25T implant, and 604.15 ± 52.49 for the 1.25TC implant. There was a significant increase in Cr.Le/B.Ar with different implant shapes (1.25C > 1.25T > 1.25TC) ($p < .05$).

Among the groups with 0.8-mm pitch, the mean values were 916.33 ± 71.69 for the 0.8C implant, 734.11 ± 192.88 for the 0.8T implant, and 478.75 ± 51.85 for the 0.8TC implant. There was a significant increase in Cr.Le/B.Ar with different implant shapes (0.8C > 0.8T > 0.8TC) ($p < .05$).

Between the groups with same implant shape, the values of the implant with 0.8-mm pitch were significantly lower than that of the implant with 1.25-mm pitch (1.25C > 0.8C, 1.25T > 0.8T, 1.25TC > 0.8TC, respectively) ($p < .05$).

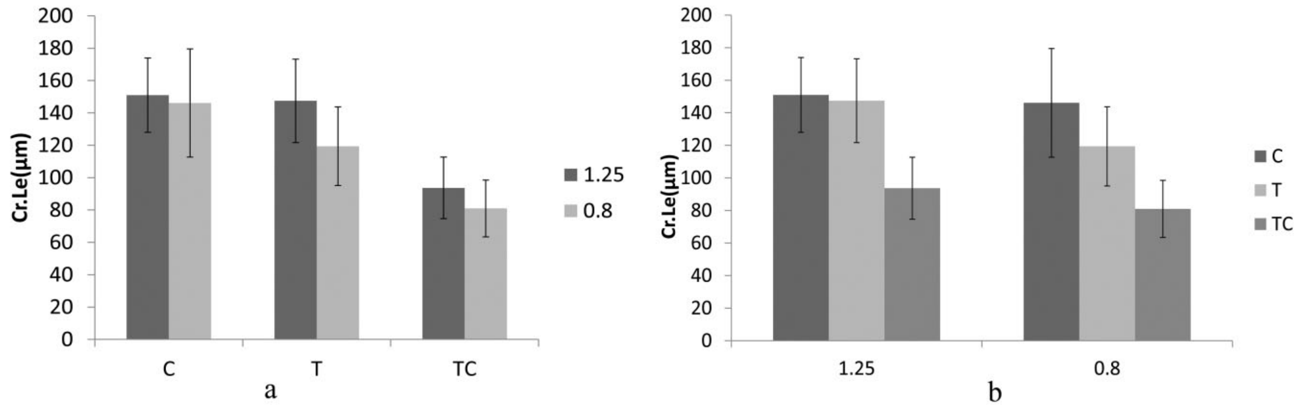

Figure 3 Length of microcrack Cr.Le (μm) (a: comparison between the implants with the same implant shape; b: comparison between the implants with the same screw pitch).

Damaged Bone Area Fraction

A column chart illustrating the damaged bone area fraction of the six groups is presented in Figure 5.

Among the groups with 1.25-mm pitch, the mean values were 10.84 ± 2.24 for the 1.25C implant, 7.48 ± 0.92 for the 1.25T implant, and 5.63 ± 0.36 for the 1.25TC implant. There was a significant increase in DB.Ar/B.Ar with different implant shapes (1.25C > 1.25T > 1.25TC) ($p < .05$).

Among the groups with 0.8 mm pitch, the mean values were 8.66 ± 0.69 for the 0.8C implant, 6.31 ± 1.02 for the 0.8T implant, and 4.40 ± 0.36 for the 0.8TC implant. There was a significant increase in DB.Ar/B.Ar with different implant shapes (0.8C > 0.8T > 0.8TC) ($p < .05$).

Between the groups with same implant shape, the values of the implant with 0.8 mm pitch were significantly lower than that of the implant with 1.25 mm pitch (1.25C > 0.8C, 1.25T > 0.8T, 1.25TC > 0.8TC, respectively) ($p < .05$).

DISCUSSION

It is considered to be ideal that all commercial implants with various macrostructure designs should be included. However, it is difficult to be accomplished in single study. Therefore, three most popular implant shapes for solid screws were introduced to this study. The implant length, core diameter, and surface characteristics were designed to be uniform to reduce the risk of confounding variables.

In order to detect microdamage in bone, a variety of methods have been applied. After being stained by different types of dyes, microdamage has been successfully observed with the help of transmitted light microscopy,

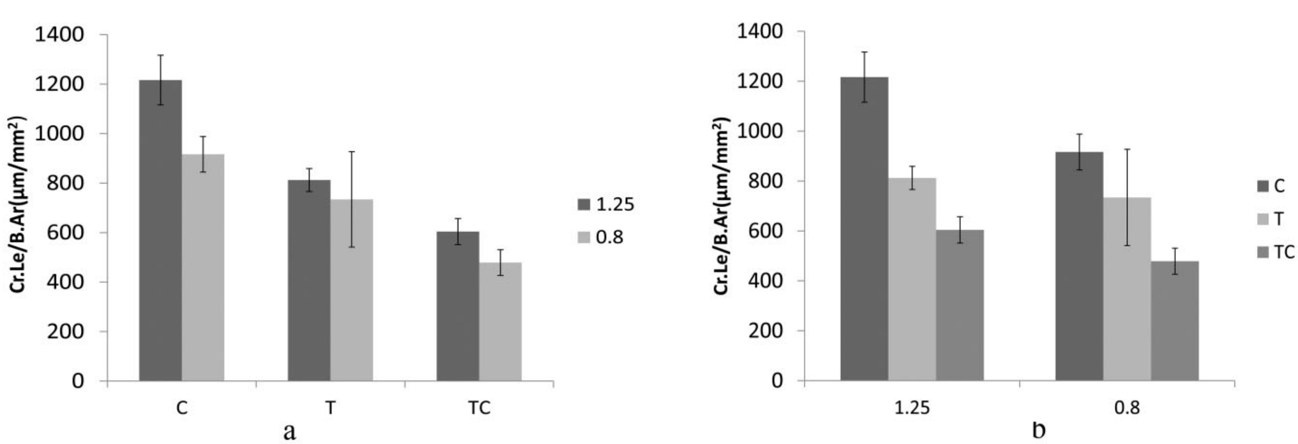

Figure 4 Microcrack surface dentsity Cr. Le/B. Ar (μm/mm²) (a: comparison between the implants with the same implant shape; b: comparison between the implants with the same screw pitch).

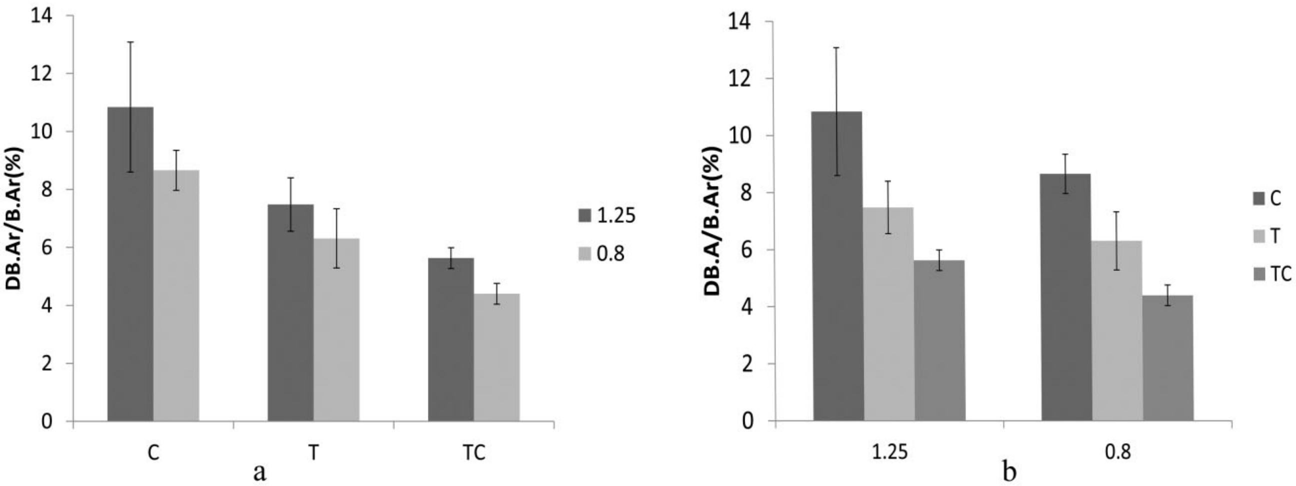

Figure 5 Damage bone area fraction DB.Ar/B Ar (%) (a: comparison between the implants with the same implant shape; b: comparison between the implants with the same screw pitch).

epifluorescence microscopy, laser scanning confocal microscopy, and micro-CT.[5,29–31] By far, the most popular method of microdamage detection has been epifluorescence, which has proved to be a rapid differentiating method for screening artifactual microdamage out from microdamage fully stained by basic fuchsin.[28] The recognition and measurement of microdamage often rely on some degree of subjective interpretation by observers. It would be better if the interobserver agreement between two independent observers could be assessed to evaluate the reliability of the data acquired.

Microdamage has been studied from the perspective of traumatology.[14,15] Microdamage has been reported to stimulate bone remodeling and repair. At any given remodeling site, bone resorption always comes before bone formation, resulting in the removal and following replacement of a quantity of bone at each site.[3,12] Under normal steady state conditions, the amount of bone remodeling is precisely replaced and there is no net change in bone mass.[13] However, microdamage, as a result of compression of the circumferential bone with implant, may break the equilibrium between damage and repair, and then eventually lead to bone resorption, local ischemia, and bone necrosis.[1,10,13] Interestingly, it has been suggested in some researches that lack of adequate mechanical stimulation, a possible result of insufficient microdamage, may lead to bone resorption. Microdamage produced within a limited range may be useful in maintaining bone mass and preventing fracture.[32,33] Although the stress ranges which induce bone to resorb, maintain, or increase its mass and the level at which induces bone to fracture have been delimitated in the literature,[34] to what extent microdamage in bone causes bone to increase its mass, maintain or to reduce its mass, and even endanger the stability of implants have not been specified. Future studies should be carried out to resolve this question.

In the current study, there were no signs of microdamage found in control groups in which only sham operations were performed. It was suggested that microdamage was generated by the placement of implant.[1,10] This result is in agreement with that of Bartold and colleagues.[2] In experimental groups, except in Cr.Le values between 1.25C and 1.25T, there were significant differences in Cr.Le, Cr.Le/B.Ar, and DB.Ar/B.Ar values among cylindrical, tapered, and taper-cylindrical implants with the same screw pitch. It indicates that implant shape has a significant effect on microdamage. Moreover, except the Cr.Le values between 1.25C and 0.8C, there were significant differences in Cr.Le, Cr.Le/B.Ar, and DB.Ar/B.Ar values between the 0.8-mm screw pitch and 1.25-mm screw pitch implants with the same implant shape. It suggests that screw pitch also has a direct effect on microdamage. Considering that the accumulation of microdamage may lead to the decline of implant stability and premature implant loss, practitioners should take implant shape and screw pitch into consideration when choosing implants. However, It should be noted that other procedures other than placement of implant also cause microdamage. It was reported in another study that the generation of most microdamage was the result of osteotomy preparation, and implant insertion made little contribution to the accumulation of microdamge in bone.[9] When osteotomy is conducted, whether implant shape and screw pitch will still be the factors that have influence on microdamage remain a problem. Therefore, the operation of osteotomy and its sequence should be considered in future studies.

Patients' desires have urged the clinicians toward immediate implant placement and earlier loading, which minimizes the inconvenience of a conventional healing period following extraction and implant placement.[24] In order to simulate the shape of the original tooth root, several dental implant systems have been created with tapered implant bodies.[23] Such implants are typically designed for situations of tooth extraction followed by immediate implant placement.[24] For the same purpose, Institute Straumann introduced the *tapered effect* (TE) implant which is the prototype of the taper-cylindrical implant created in the present study. This kind of implant has been used in practice in immediate postextraction cases and also been found advantageous in type 3 or 4 bone for its higher primary stability.[35] It is prostulated that primary stability is enhanced by the compressive forces induced by inserting the coronal tapered part into the standard parallel-sided hole during implant placement.[25] The results of the current study showed that taper-cylindrical implants generated the least amount of microdamage during implant insertion. This finding may explain the phenomenon that ITI TE implants showed advantages in lowering the risk of fracture of the labial cortical plate during implant insertion in conjunction with split crest technique. The success rates of ITI TE implants were 100%, while the success rates were 95% for the standard cylindrical implants.[36] The current study also demonstrated that the insertion of cylindrical implants resulted in an increase of microdamage in comparison with tapered implants, which is in accordance with the findings in the study by Bartold and colleagues.[2]

To date, no study has assessed the influence of screw pitch on the generation of microdamage during the placement of implant. In the current study, results showed that increased screw pitch resulted in increased values of Cr.Le, Cr.Le/B.Ar, and DB.Ar/B.Ar. The contact area between implant and the bone decreased with the increase of screw pitch. The decreased contact area may increase the stress, which could lead to the generation of microdamage.

In conclusion, taper-cylindrical implants with 0.8 mm-screw pitch caused the least microdamage to the bone during placement of implants. This type of implant may be an ideal design to prevent the early failure from the perspective of traumatology. Further studies are required to investigate the long-term influence of implant shape and screw pitch on microdamage after functional loading.

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