

# Effects of a New Implant Abutment Design on Peri-Implant Soft Tissues

Hua-Hong Chien, DDS, PhD<sup>1\*</sup>  
 Robert L. Schroering, DMD<sup>2</sup>  
 Hari S. Prasad, BS, MS, MDT<sup>3</sup>  
 Dimitris N. Tatakis, DDS, PhD<sup>1</sup>

The purpose of this study was to assess the effects of a modified implant abutment design on peri-implant soft and hard tissues in dogs. Three months after extraction of mandibular premolar teeth, 3 dental implants were placed in each side of the jaw using a 1-stage approach. Implants on one side of the mandible received standard abutments (control), and implants on the contralateral side received modified, patented, grooved abutments (test). Two months after implant placement, animals were euthanized and specimens were prepared for histologic and histomorphometric assessment. The linear distance (in micrometers) was measured from the implant shoulder (IS) to the following landmarks: gingival margin (GM; distance IS-GM), most apical position of the junctional epithelium (JE; distance IS-JE), and bone crest (BC; distance IS-BC). Percent of bone-to-implant contact was also measured. Histologic assessment revealed that all implants were osseointegrated and that interimplant gingival fibers between test abutments appeared to be more numerous and organized than control abutments. The IS-GM and IS-JE distances in test implants were greater than the corresponding distances in control implants ( $P = .024$  and  $P = .015$ , respectively), whereas crestal bone loss (IS-BC) was greater for control implants than test implants ( $P = .037$ ). There were no differences between control and test implants in bone-to-implant contact ( $P = .69$ ), which averaged close to 50%. These results suggest that the modified groove design incorporated in standard abutments confers both soft and hard tissue benefits.

**Key Words:** *nonsubmerged healing, healing abutment, crestal bone, peri-implant soft tissues, light microscopy*

## INTRODUCTION

Osseointegrated implants have become a viable, if not routine, treatment option for completely and partially edentulous patients. Since the classic studies of Branemark et al,<sup>1</sup> implant treatment has shown good success and prognosis when used within the defined treatment parameters. Continual improvements in surface properties and material composition have advanced

osseointegration to an even higher success level. In contrast to the more than 40 years of research and innovation focusing on bone-to-implant contact (BIC), the emphasis on the importance of the peri-implant soft tissues and their attachment to the dental implant or implant abutment is much more recent.<sup>2</sup> The key element in the success of dental implants is maintenance of the integration between intraoral tissues and the implant.<sup>3</sup> Studies have shown that breakdown of the tissue/implant interface initiates in the crestal region of otherwise successfully integrated implants.<sup>4</sup> Among the many hypotheses that have been postulated as reasons for these early crestal bony changes, the establishment of an implant "biologic width" is one that implicates the peri-implant soft tissues.<sup>5,6</sup>

The structure of the soft tissues surrounding

<sup>1</sup> Division of Periodontology, College of Dentistry, The Ohio State University, Columbus, Ohio.

<sup>2</sup> Private Practice, Chandigarh, India.

<sup>3</sup> Hard Tissue Research Laboratory, University of Minnesota School of Dentistry, Minneapolis, Minn.

\* Corresponding author, e-mail: chien.60@osu.edu

DOI: 10.1563/AAID-JOI-D-12-00313

dental implants is, in many ways, analogous to the natural tooth.<sup>7</sup> The main difference from the natural dentition is the manner in which the peri-implant connective tissue interfaces with the implant or implant abutment. The tooth contains Sharpey's fibers that connect cementum to the periodontal ligament and bone. These fibers help form a physical attachment from the natural tooth to the surrounding tissue.<sup>7</sup> This type of physical attachment is absent around a dental implant or implant abutment, which can lead to a gingiva-to-implant contact that may not be as strong or as stable as the gingiva-to-tooth connection. It is thought that this different attachment of the gingiva to the implant/abutment manifests itself in a high incidence of recession in the first 6 months after dental implant placement, with a recorded magnitude greater than 1 mm in apical movement.<sup>8</sup> The complications associated with peri-implant soft tissue recession can be significant, from esthetically poor clinical results to possible exposure of the dental implant and long-term failure.

Most recent evidence suggests that modifications of the abutment (or transmucosal implant portion) surface can affect peri-implant gingival tissue healing, composition, and postoperative stability.<sup>9</sup> Earlier studies indicate that implant surface topography can alter the behavior of cells in vitro,<sup>10</sup> which can be exploited to design implants that promote connective tissue ingrowth and thus minimize epithelial downgrowth in vivo;<sup>11</sup> more specifically, Chehroudi et al<sup>11</sup> showed the advantage of using 19 µm or 30 µm grooves or 120 µm deep tapered pits to take advantage of the circular system of collagen fibers that form around the connective tissue layer of a transcutaneous implant. Therefore, the possibility exists that incorporating defined grooves in the transmucosal aspect of an implant (or abutment) might improve the relationship between the peri-implant soft tissues and the implant/abutment, which in turn might result in improved crestal bone level stability. Such an approach, however, has not been tested and quantitatively analyzed in the oral cavity.

The purpose of the present study was to examine the peri-implant soft tissue and crestal bone response toward a new implant abutment design based on a patented design intended to take advantage of groove-directed collagen tissue ingrowth and to compare it with the peri-implant

soft tissue and crestal bone response toward a standard abutment.

## MATERIALS AND METHODS

### *Experimental design*

Adult dogs received implants in the mandible. The study was a split-mouth design to allow within-animal comparisons of test and control implants that have healed for 2 months (Figure 1). After tooth extraction and a 3-month healing period, implants were placed under a 1-stage protocol. Animals were euthanized 2 months after the implant placement procedure.

### *Study animals*

The study protocol was approved by the Institutional Lab Animal Care and Use Committee of the Ohio State University. Three adult ( $\geq 12$  months old; weight 20–25 kg) male beagle dogs, obtained from a commercial vendor, were used in the study.

### *Surgical procedures and postoperative protocols*

#### *Tooth Extraction*

Tooth extractions were performed under general anesthesia and sterile conditions in an operating room using 4% thiopental sodium intravenous solution (0.4 mL/kg by weight) as a premedication. The dogs, placed on a heating pad, were intubated and inhaled with 1.5% to 2% isoflurane and monitored during surgery. After disinfection of the surgical site with 10% povidone-iodine solution/1% titrable iodine, 2% lidocaine HCl with epinephrine 1:100 000 was administered and all 4 mandibular premolars (P<sub>1</sub>–P<sub>4</sub>) were sectioned and carefully extracted, and the ridge height reduced by 2–3 mm, to produce a ridge of continuous 4-mm width. Flaps were sutured with monofilament absorbable sutures. After a 3-month healing period, implants were placed.

#### *Postoperative Protocol*

The same postoperative protocol was used for tooth extraction and implant placement. The day of the surgery, animals received 20 mg of the analgesic nalbuphine subcutaneous (10 mg/mL, twice a day). Prophylactic antibiotics (enrofloxacin; 2.5 mg/kg by weight; intramuscular) was administered immediately postoperatively and then twice a

day for 7 days after surgery. A soft diet was used for the duration of the study. In addition, oral hygiene procedures were carried out 3 times a week using a 0.2% chlorhexidine gel in combination with a soft toothbrush and a soft sponge.

### *Implant Surgery*

After a healing period of 3 months after tooth extraction (Figure 1), 6 root-form bone-level implants (Blue Sky Bio LLC, Greyslake, Ill) were placed in the mandible, 3 on each side (left/right). The implants, inserted under the same surgical conditions as tooth extraction, were placed under a 1-stage protocol and in such a manner that the implant platform was at the level of the crest interproximally. Implants received specific abutments as outlined in the following sections and then flaps were sutured. One side of the mandible in each dog received 3 smooth (control) abutments, and the contralateral side received 3 patented, grooved abutments (test; ActivFlour surface, Blue Sky Bio LLC). In this manner, the study included 9 test and 9 control implants, followed for 2 months of healing.

For implant placement, a crestal incision was made, maximizing keratinized tissue on each side of the incision. Mucoperiosteal flaps were carefully reflected on the lingual and buccal aspect. The 3 implants were evenly distributed on the side of the mandible. Implant osteotomies and insertions were performed with torque reduction rotary instruments following a standard protocol. After implant placement, abutments were connected to the implants. Flap closure was then achieved with monofilament absorbable sutures, and care was taken to achieve tension-free wound closure while properly adapting the soft tissues around the transmucosal abutments. The postoperative protocol was the same as described earlier for tooth extraction.

### **Specimen harvest**

Two months after implant placement surgery all animals were euthanized. Euthanasia was performed with an overdose of pentobarbital sodium intravenous (0.2 mL = 65 mg/kg by weight). Mandibles were block-resected with an oscillating autopsy saw, and the recovered gross specimens with the implants were rinsed in saline and placed in 10% neutral buffered formalin for histologic preparation and analysis.

## **Specimen preparation and analysis**

### *Histology*

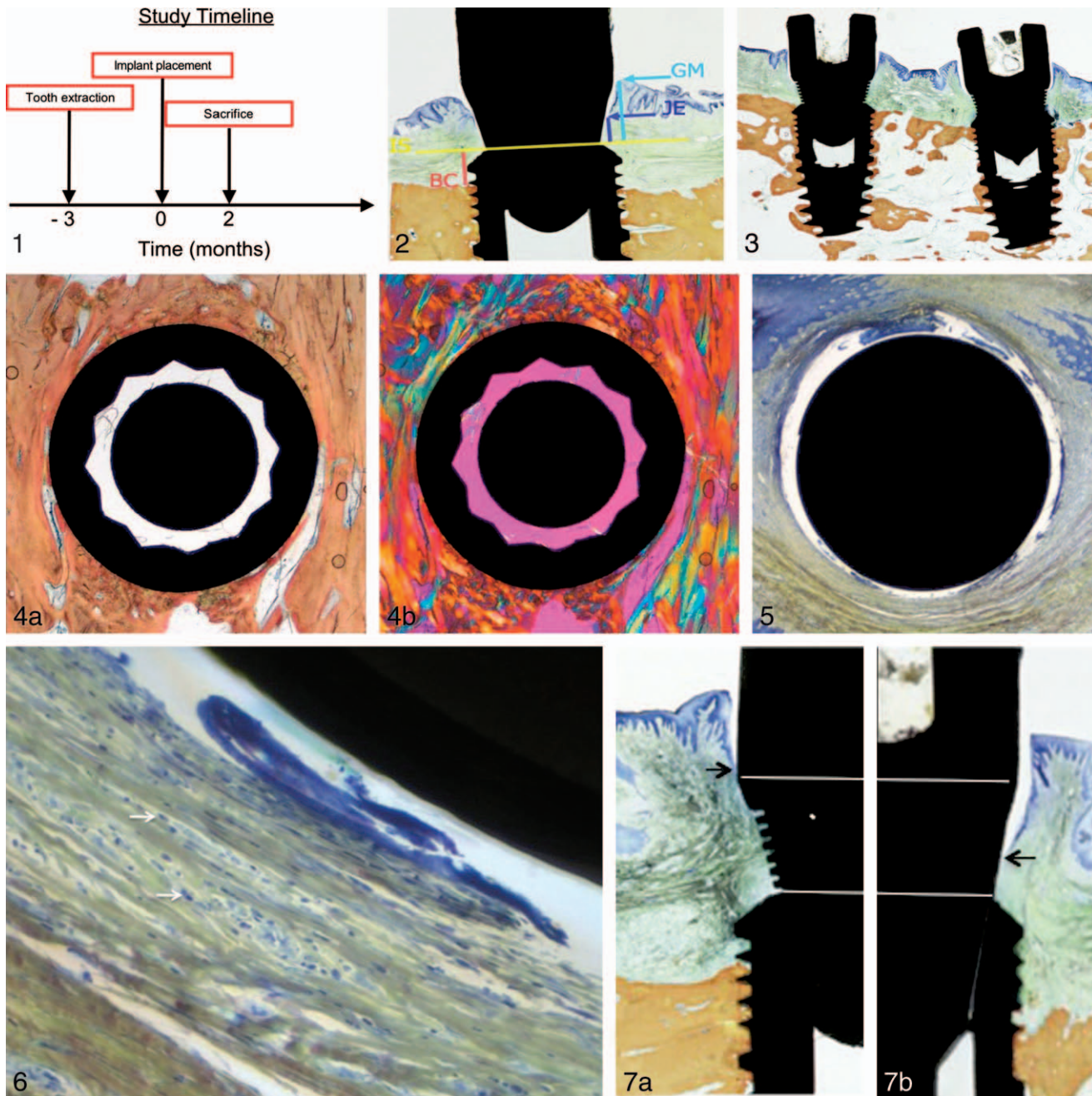
From each hemimandible, 2 gross specimens were prepared; a mesial specimen containing the 2 most mesial implants (2-implant block) and a distal block containing the third (most distal) implant (single-implant block). The 2 mesial implants were processed together in the same block, and the distal implant was processed separately.

The formalin-treated 2-implant specimens were sectioned vertically in an anterior/posterior (mesial/distal) orientation according to protocol specifications. Immediately after sectioning, specimens were dehydrated with a graded series of alcohols for 9 days. After dehydration, the specimens were infiltrated with a light-curing embedding resin (Technovit 7200 VLC, Kulzer, Wehrheim, Germany). After 20 days of infiltration with constant shaking at normal atmospheric pressure, the specimens were embedded and polymerized by 450 nm light, during which time the specimens' temperature never exceeded 40°C. The specimens were then prepared by the cutting/grinding method of Donath and Breuner<sup>12</sup> and Rohrer and Schubert.<sup>13</sup> The specimens were cut to a thickness of 150 µm on an Exakt cutting/grinding system (Exakt Technologies, Oklahoma City, Okla). After this, specimens were polished to a thickness of 45–65 µm using a series of polishing sandpaper discs from 800 to 2400 grit using an Exakt micro-grinding system followed by a final polish with 0.3 µm alumina polishing paste. The slides were then stained with Stevenel blue and Van Gieson picro fuchsin and coverslipped for histologic analysis by means of bright field and polarized microscopic evaluation. At least 2 sections per block were available for evaluation. The single implant (distal) blocks were processed in the same manner, except that the implants were sectioned transversely.

### *Histomorphometry*

Sections were digitized at the same magnification using a Nikon Eclipse 50i microscope (Nikon Instruments, Inc, Melville, NY) and a Spot Insight 2-megapixel color digital camera (Diagnostic Instruments, Inc, Sterling Heights, Mich). Histomorphometric measurements were completed using a combination of the Spot Insight program and Adobe PhotoShop (Adobe Systems, Inc, San Jose,





**FIGURES 1–7. FIGURE 1.** Study timeline. **FIGURE 2.** Schematic drawing illustrating the landmarks used for histomorphometric measurements. IS indicates implant shoulder, the abutment/fixture borderline; GM, gingival margin, the marginal portion of the peri-implant mucosa; JE, junctional epithelium, the most apical termination of the JE; BC, bone crest, the marginal level of bone-to-implant contact. **FIGURE 3.** Light microscopic view of a representative jaw specimen demonstrating osseointegrated implants with test abutments. Note the apical end of the JE positioned at or coronal to the first abutment surface groove. (Stevenel blue and Van Gieson picro fuchsin; magnification  $\times 10$ ). **FIGURE 4.** (a) Left, transversely sectioned implant (transmission light). Note the intimate bone to implant contact. (b) Right, the same section (polarized light). Note the diverse orientation of the lamellar bone collagen fibers (different color and brightness) (Stevenel blue and Van Gieson picro fuchsin; magnification  $\times 25$ ). **FIGURE 5.** Transverse section of a test abutment demonstrating dense circular fibers surrounding the grooved abutment (Stevenel blue and Van Gieson picro fuchsin; magnification  $\times 25$ ). **FIGURE 6.** At a higher magnification of the test abutment specimen shown in Figure 5, it is possible to note the collagen fibers (stained light green) and the associated fibroblastic cells (arrows) near the abutment surface (Stevenel blue and Van Gieson picro fuchsin; magnification  $\times 200$ ). **FIGURE 7.** Light microscopic view of the peri-implant tissues around (a) a test and (b) a control abutment in the same animal. The specimens demonstrate differences in density and orientation of the gingival connective

Calif). At least 2 slides were evaluated for each specimen.

Measurements were obtained from each 2-implant section, as follows:

1. Implant shoulder (IS) to gingival margin (GM) in microns (Figure 2, light blue line)
2. IS to the most apical position of the junctional epithelium (JE) in microns (Figure 2, dark blue line)
3. IS to bone crest (BC), that is, the marginal level of BIC, in microns (Figure 2, red line).

In addition, BIC, that is, the percentage of the implant surface that was in contact with bone, was calculated from the same blocks. The distal implant from each hemimandible was sectioned transversely to document the presence, orientation, position, and abundance of circular fibers.

### **Data analysis**

The unit of statistical analysis was the implant. The measurements (IS-GM, IS-JE, IS-BC, and BIC) from the mesial and distal aspect of every implant were averaged to provide a mean for the implant for the specific section. The respective values from the 2 sections were averaged to obtain a mean value for the implant. Descriptive statistics were calculated for measured parameters. A 2-tailed paired *t* test was used to compare the differences between test and control implants. Statistical significance was set at  $P = .05$

## **RESULTS**

### **Clinical observations**

The surgical procedures were completed uneventfully, and the postoperative course of the animals was without complications. Soft tissue healing was within normal limits. There were no signs of implant or abutment mobility at any time after implant placement.

### **Histologic findings**

All implant specimen blocks were processed and available for evaluation. Under transmission light

microscopy, the histologic appearance of all implants indicated appropriate osseointegration (Figure 3). Under higher magnification, the implant surfaces were in close contact with vital bone, and several areas exhibited active bone formation.

The presence of trabecular bone in contact with the implants could be readily seen on the transversely sectioned implants (Figure 4a). The intimate BIC was confirmed when various sections were examined under polarized light microscopy, where it was observed that lamellar bone was in close contact with the implant surface (Figure 4b). There were no discernible differences between control and test implants regarding the aforementioned histologic observations.

The transversely sectioned implants were not amenable to any further assessment regarding soft tissue histology. Unfortunately, this was because the sections were not made at the required position; that is, most of the sections were made at or below the crest. The single test implant sectioned at the JE level showed dense circular fibers surrounding the abutment (Figure 5).

Under higher magnification, the organization of the circular gingival fibers (Figure 6, stained light green) and the associated fibroblastic cells (Figure 6, stained blue), can be better appreciated in close proximity to the test abutment (Figure 6).

The histologic appearance of the supracrestal, interimplant gingival fibers suggested that the collagen fibers between the test-side abutments were more dense and organized compared with the control-side abutments. Under higher magnification, it was possible to observe that the collagen fiber bundles were perpendicularly or obliquely oriented toward the test abutment surface (Figure 7a), whereas the corresponding fiber bundles were oriented parallel to the control abutment surface (Figure 7b).

### **Histomorphometric measurements**

Histomorphometric analysis revealed statistically significant differences between test and control abutments in 3 of the 4 parameters assessed (Table). The GM and the apical end of the JE were

← tissue fibers: dense connective tissue fibers are oriented perpendicular to the test abutment surface (a), and less dense fibers are oriented parallel to the control abutment surface (b). Apical migration of the epithelium, resulting in a long JE is evident on the control abutment surface (b). The apical end of the JE (black arrows) is located closer to the implant-abutment junction in the control abutment (Stevenel blue and Van Gieson picro fuchsin; magnification  $\times 25$ ).

TABLE  
Histomorphometric measurements\*

Parameter†	Test (n = 6) Mean ± SD	Control (n = 6) Mean ± SD	P Value‡
IS-GM (µm)	1932 ± 398	1561 ± 175	<b>.0244</b>
IS-JE (µm)	885 ± 296	456 ± 117	<b>.0148</b>
IS-BC (µm)	456 ± 229	954 ± 356	<b>.0371</b>
BIC (%)	51 ± 10	52 ± 2	.69

\*The landmarks used for the measurements are described in Figure 2.

†IS indicates implant shoulder; GM, gingival margin; JE, junctional epithelium; BC, bone crest; BIC, bone-to-implant contact.

‡Bold numbers denote statistical significance at  $P < .05$ .

more distant from the IS and more coronal in the test implants compared with the control implants. The most coronal point of BIC was more distant from the IS, and more apical in the control implants compared with the test implants. A representative depiction of such results in the same animal is shown in Figure 7. The percentage of BIC was not different between test and control implants.

### DISCUSSION

The present pilot animal study sought to determine possible differences in hard and soft tissue behavior around implants placed under a 1-stage protocol with either routine, smooth abutments (control) or patented, grooved abutments (test). The results show that, after the first 2 months of healing, use of test abutments is associated with significantly less crestal bone resorption and significantly more coronal position of the apical end of the JE without any effect on implant osseointegration. These results suggest that altered abutment surface topography might help determine the formation of a more desirable soft tissue healing, which prevents epithelial downgrowth and, consequently, prevents or limits crestal bone resorption.

It has been well established from in vitro studies that the physiologic behavior of cells, such as fibroblasts and osteoblasts, is significantly affected by the surface topography of the substratum.<sup>14-17</sup> These observations have led to clinical applications; for example, results from in vivo studies suggest that incorporating microgrooves on a dental implant collar results in decreased marginal bone loss.<sup>18-20</sup>

The soft tissue attachment around dental implants or abutments consists of an epithelial zone and a connective tissue zone, represented by

the JE and the gingival connective tissue, respectively. The height of the suprabony connective tissue can vary between 1.3 and 1.8 mm.<sup>6</sup> Buser and colleagues<sup>21</sup> described the gingival connective tissue contact to nonsubmerged titanium implants in dogs; an approximate 50–100 µm wide zone of dense circular fibers was located directly adjacent to the implant surface above the alveolar bone. This zone did not contain blood vessels and was envisioned as scar tissue without inflammatory cells. Schierano et al<sup>22</sup> studied collagen fiber orientation around the implant stem as it exited the bone; collagen bundles were abundant all around the implant, with a maximum density between 200 and 800 µm from the abutment surface. These bundles were organized in 3 different patterns: (1) circular fibers, the most common type in all samples, usually observed 200–800 µm from the abutment surface; (2) longitudinal fibers, in smaller numbers, observed in the longitudinal sections in the first 200 µm from the abutment surface; and (3) oblique fibers, in small separate bundles, which could be observed externally to the above systems with variable orientation.<sup>22</sup> Other investigators have made similar observations.<sup>23</sup> From a clinician’s perspective, it is common to observe that, within a few minutes after the removal of a healing abutment from an implant, the soft tissue opening to the dental implant is constricted; this is attributed to the action of the circular fibers. The presence of a dominant circular system of collagen fibers around the abutment is in accordance with the concept of peri-implant “circular ligament” proposed by Ruggeri et al<sup>24</sup> and confirmed by Piattelli et al.<sup>25</sup> This circular ligament helps form a tight seal around the abutment/transmucosal portion of the implant.

The effects of abutment component surface



characteristics on epithelial, fibroblastic, and osteoblastic cell behavior have been examined at the implant-abutment interface.<sup>9,26,27</sup> Abrahamsson et al<sup>27</sup> examined histologically, using a canine model, the soft tissue attachment to abutments made from titanium, gold alloy, ceramic, or dental porcelain. They found that titanium and ceramic abutments had the longest attachment; however, no proper attachment was formed on gold alloy or dental porcelain abutments, resulting in marked soft tissue recession and bone resorption. These results highlight the significance of material properties for the establishment of peri-implant soft tissue attachment.

Beyond material type, the surface topography of the transmucosal (or transcutaneous) component (whether a separate abutment or part of the implant) can significantly affect the soft tissue response.<sup>11,28,29</sup> Most recently, a human histologic case report<sup>28</sup> and a canine study<sup>29</sup> using laser-microgrooved abutments reported the presence of connective tissue fibers inserted directly on the abutment surfaces. However, neither of these studies<sup>28,29</sup> quantified the soft or hard tissue response. The control and test abutments used in the present study were made of the same material, with control abutments having a smooth surface texture and test abutments having a modified surface texture, characterized by the incorporation of small grooves. The grooved abutments, compared with the control abutments, prevented approximately 0.5 mm of crestal bone loss and 0.4 mm of epithelial downgrowth (Table). In contrast to our results and those of Nevins et al,<sup>28,29</sup> Weinlander et al<sup>30</sup> reported that incorporating a macrogroove in the abutment design does not confer beneficial effects in terms of hard or soft tissue outcomes. Therefore, the dimensional aspects of the altered abutment surface topography are critical in conferring better soft tissue attachment and, consequently, peri-implant soft and hard tissue stability.

Another modification that results in greater marginal bone stability is the one introduced by Lazzara and Porter,<sup>31</sup> who used abutments of diameter smaller than the implant diameter; the concept of platform switching, in which a smaller-diameter prosthetic component is connected to a larger-diameter implant platform to increase the distance between inflammatory cell infiltrate and alveolar bone crest, is supported by a recent

systematic review and meta-analysis.<sup>32</sup> However, long-term and randomized controlled studies are required to validate the platform-switching concept. The results suggest that preservation of crestal bone height and soft tissue level can be affected by the relative size of the abutment (eg, platform switching) and the surface topography of the abutment (eg, the present study and other recent studies on grooved abutments<sup>28,29</sup>). The possible future combination of these 2 concepts could result in significant improvement in implant therapy clinical outcomes.

## CONCLUSIONS

Within the limitations of this study, the findings indicate that the patented groove design incorporated in routine abutments confers both soft and hard tissue benefits. Consequently, this grooved abutment design merits further assessment in a clinical setting. The long-term stability of the favorable soft and hard tissue outcomes associated with this type of abutment surface topography remains to be established.

## ABBREVIATIONS

BC: bone crest  
 BIC: bone-to-implant contact  
 GM: gingival margin  
 IS: implant shoulder  
 JE: junctional epithelium

## ACKNOWLEDGMENTS

The authors thank Dr I. N. Tsolaki and the staff of the OSU Animal Care Facilities for their kind assistance with animal care. This study was supported by a research contract funded by one of the authors (R.L.S.), who is the patent holder.

## REFERENCES

1. Branemark PI, Hansson BO, Adell R, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. *Scand J Plast Reconstr Surg Suppl.* 1977;16:1–132.
2. Rompen E, Domken O, Degidi M, Pontes AE, Piattelli A. The effect of material characteristics, of surface topography and of implant components and connections on soft tissue integration: a literature review. *Clin Oral Implants Res.* 2006;17(suppl 2):55–67.
3. Schroeder A, van der Zypen E, Stich H, Sutter F. The

reactions of bone, connective tissue, and epithelium to endosteal implants with titanium-sprayed surfaces. *J Maxillofac Surg.* 1981;9:15–25.

4. Adell R, Lekholm U, Rockler B, Branemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg.* 1981;10:387–416.

5. Abrahamsson I, Berglundh T, Wennstrom J, Lindhe J. The peri-implant hard and soft tissues at different implant systems. A comparative study in the dog. *Clin Oral Implants Res.* 1996;7:212–219.

6. Berglundh T, Lindhe J. Dimension of the periimplant mucosa. Biological width revisited. *J Clin Periodontol.* 1996;23:971–973.

7. Listgarten MA, Lang NP, Schroeder HE, Schroeder A. Periodontal tissues and their counterparts around endosseous implants [corrected and republished with original paging, article originally printed in. *Clin Oral Implants Res.* 1991;2:1–19. *Clin Oral Implants Res.* 1991;2:1–19.

8. Bengazi F, Wennstrom JL, Lekholm U. Recession of the soft tissue margin at oral implants. A 2-year longitudinal prospective study. *Clin Oral Implants Res.* 1996;7:303–310.

9. Welander M, Abrahamsson I, Berglundh T. The mucosal barrier at implant abutments of different materials. *Clin Oral Implants Res.* 2008;19:635–641.

10. Brunette DM. The effects of implant surface topography on the behavior of cells. *Int J Oral Maxillofac Implants.* 1988;3:231–246.

11. Chehroudi B, Gould TR, Brunette DM. The role of connective tissue in inhibiting epithelial downgrowth on titanium-coated percutaneous implants. *J Biomed Mater Res.* 1992;26:493–515.

12. Donath K, Breuner G. A method for the study of undecalcified bones and teeth with attached soft tissues. The Sage-Schliff (sawing and grinding) technique. *J Oral Pathol.* 1982;11:318–326.

13. Rohrer MD, Schubert CC. The cutting-grinding technique for histologic preparation of undecalcified bone and bone-anchored implants. Improvements in instrumentation and procedures. *Oral Surg Oral Med Oral Pathol.* 1992;74:73–78.

14. Brunette DM, Chehroudi B. The effects of the surface topography of micromachined titanium substrata on cell behavior in vitro and in vivo. *J Biomech Eng.* 1999;121:49–57.

15. Furuhashi A, Ayukawa Y, Atsuta I, Okawachi H, Koyano K. The difference of fibroblast behavior on titanium substrata with different surface characteristics. *Odontology.* 2012;100:199–205.

16. Chehroudi B, Gould TR, Brunette DM. A light and electron microscopic study of the effects of surface topography on the behavior of cells attached to titanium-coated percutaneous implants. *J Biomed Mater Res.* 1991;25:387–405.

17. Kononen M, Hormia M, Kivilahti J, Hautaniemi J, Thesleff I. Effect of surface processing on the attachment, orientation, and proliferation of human gingival fibroblasts on titanium. *J Biomed Mater Res.* 1992;26:1325–1341.

18. Botos S, Yousef H, Zweig B, Flinton R, Weiner S. The effects

of laser microtexturing of the dental implant collar on crestal bone levels and peri-implant health. *Int J Oral Maxillofac Implants.* 2011;26:492–498.

19. Pecora GE, Ceccarelli R, Bonelli M, Alexander H, Ricci JL. Clinical evaluation of laser microtexturing for soft tissue and bone attachment to dental implants. *Implant Dent.* 2009;18:57–66.

20. Weiner S, Simon J, Ehrenberg DS, Zweig B, Ricci JL. The effects of laser microtextured collars upon crestal bone levels of dental implants. *Implant Dent.* 2008;17:217–228.

21. Buser D, Weber HP, Donath K, Fiorellini JP, Paquette DW, Williams RC. Soft tissue reactions to non-submerged unloaded titanium implants in beagle dogs. *J Periodontol.* 1992;63:225–235.

22. Schierano G, Ramieri G, Cortese M, Aimetti M, Preti G. Organization of the connective tissue barrier around long-term loaded implant abutments in man. *Clin Oral Implants Res.* 2002;13:460–464.

23. Comut AA, Weber HP, Shortkroff S, Cui FZ, Spector M. Connective tissue orientation around dental implants in a canine model. *Clin Oral Implants Res.* 2001;12:433–440.

24. Ruggeri A, Franchi M, Marini N, Trisi P, Piatelli A. Supracrestal circular collagen fiber network around osseointegrated nonsubmerged titanium implants. *Clin Oral Implants Res.* 1992;3:169–175.

25. Piatelli A, Scarano A, Piattelli M, Bertolai R, Panzoni E. Histologic aspects of the bone and soft tissues surrounding three titanium non-submerged plasma-sprayed implants retrieved at autopsy: a case report. *J Periodontol.* 1997;68:694–700.

26. Zitzmann NU, Abrahamsson I, Berglundh T, Lindhe J. Soft tissue reactions to plaque formation at implant abutments with different surface topography. An experimental study in dogs. *J Clin Periodontol.* 2002;29:456–461.

27. Abrahamsson I, Berglundh T, Glantz PO, Lindhe J. The mucosal attachment at different abutments. An experimental study in dogs. *J Clin Periodontol.* 1998;25:721–727.

28. Nevins M, Camelo M, Nevins ML, Schupbach P, Kim DM. Connective tissue attachment to laser-microgrooved abutments: a human histologic case report. *Int J Periodontics Restorative Dent.* 2012;32:385–392.

29. Nevins M, Kim DM, Jun SH, Guze K, Schupbach P, Nevins ML. Histologic evidence of a connective tissue attachment to laser microgrooved abutments: a canine study. *Int J Periodontics Restorative Dent.* 2010;30:245–255.

30. Weinlander M, Lekovic V, Spadijer-Gostovic S, Milicic B, Wegscheider WA, Piehlinger E. Soft tissue development around abutments with a circular macro-groove in healed sites of partially edentulous posterior maxillae and mandibles: a clinical pilot study. *Clin Oral Implants Res.* 2011;22:743–752.

31. Lazzara RJ, Porter SS. Platform switching: a new concept in implant dentistry for controlling postrestorative crestal bone levels. *Int J Periodontics Restorative Dent.* 2006;26:9–17.

32. Atieh MA, Ibrahim HM, Atieh AH. Platform switching for marginal bone preservation around dental implants: a systematic review and meta-analysis. *J Periodontol.* 2010;81:1350–1366.