

Biologic Width Around Titanium Implants. A Histometric Analysis of the Implanto-Gingival Junction Around Unloaded and Loaded Nonsubmerged Implants in the Canine Mandible

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THE USE OF ENDOSSEOUS DENTAL IMPLANTS as transmucosal devices necessitates the successful integration of three different tissues: bone, connective tissue, and epithelium. So far, studies have predominantly focused on hard tissue integration. Much less is known about soft tissues. This study examined the dimensions of the implanto-gingival junction in relation to clinically healthy unloaded and loaded nonsubmerged implants. In total, 69 titanium plasma-sprayed (TPS) and sandblasted acid-etched (SLA) implants were placed in an alternating fashion in six foxhounds and allowed to heal for 3 months. Two dogs were sacrificed after the initial healing period. The remaining four dogs had crowns fabricated that were allowed to function for up to 12 months. These animals were sacrificed after 3 and 12 months of loading. Histometric analysis of undecalcified histologic sections included the evaluation of the sulcus depth (SD), the dimensions of the junctional epithelium (JE), and the connective tissue contact (CTC). Mean values in the 3 month unloaded group were 0.49 mm for SD, 1.16 mm for JE, and 1.36 mm for CTC. These dimensions were 0.50 mm for SD, 1.44 mm for JE, and 1.01 mm for CTC for the 3 month loaded group. After 12 months of loading, these values were 0.16 mm for SD, 1.88 mm for JE, and 1.05 mm for CTC. The sum of these measurements was similar for the different time points and similar to the same dimensions around teeth. TPS and SLA surfaces had no influence on the evaluated parameters ($P > 0.05$). The data suggest that a biologic width exists around unloaded and loaded nonsubmerged one-part titanium implants and that this is a physiologically formed and stable dimension as is found around teeth. *J Periodontol* 1997; 68:186-198.

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In the past 25 years, basic research in implant dentistry has focused mainly on the bone-to-implant interface of endosseous implants. This has been primarily due to the fact that predictable implant anchorage requires direct bone-to-implant contact. Original investigations examined

parameters of surgical procedures and characteristics of implant shape and surface to achieve hard tissue integration. Brånemark et al.¹ using submerged implants established criteria to predictably achieve direct bone-to-implant contact called "osseointegration." Schroeder et al.^{2,3} utilizing intentionally nonsubmerged implants recognized that oral implants must integrate with three tissues; namely, bone, connective tissue, and epithelium. These investigators examined parameters for a bone-to-implant contact, called "functional ankylosis," and, in addition, described for the first time histologically the contact of soft tissues to the transmucosal portion of titanium implants.⁴

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One of the prerequisites for successful implant integration recommended by Brånemark et al.¹ was to cover the implant with soft tissues. After an initial healing period, another implant component, following a second surgical procedure, was placed on the submerged implant. This component penetrated the soft tissues resulting in a transmucosal device. Thus, a space or gap always exists between implant and abutment at or below the osseous crest. A rationale for the need for submerging the implant was due to "occasionally" exposed implants to the oral cavity.¹ No numbers were given as to the percentage that became exposed. Furthermore, no oral hygiene procedures were performed on these animals. Thus, plaque accumulated and inflammation was found on the exposed implants compared to implants covered by soft tissues. Brånemark et al.,^{1,5} therefore, recommended submerging endosseous implants below the soft tissues in order to achieve osseous integration. Albrektsson⁶ in a review of this work stated that the soft tissues over the submerged implant provided "... a barrier toward downgrowth of granulation tissue during the phase of bone demineralization. . ." However, in a later paper by Albrektsson and Sennerby,⁷ these authors suggested "... there is insufficient evidence to back up the necessity for a 2-stage surgical procedure . . ." Ruggeri et al.⁸ stated that their results from studies on supracrestal collagen fibers around nonsubmerged implants disagree with previous findings that submerged implants are required to avoid local inflammation and epithelial downgrowth. In a later article by Ruggeri et al.⁹ they conclude, "... keeping an implant nonsubmerged at the time of surgical placement does not influence its survival . . ." Thus, there are conflicting data on soft tissues around endosseous implants.

Transmucosal devices in the oral cavity must penetrate the soft tissues comprised of gingival connective tissue and gingival epithelium. Therefore, implants should form a seal at the soft tissue interface to ensure the integrity of the integument. The implanto-gingival tissues by definition thus have to serve a similar barrier function as dento-gingival tissues, and integration of an implant necessitates the integration of all three types of tissue—bone, connective tissue, and epithelium. Many longitudinal clinical studies have shown that both submerged and nonsubmerged implants can be clinically successful.^{5,10-21} It has also been shown that there is no difference in the hard tissue healing when comparing submerged and nonsubmerged implants.²² Gingival connective tissue appears to form a scar-like connective tissue contact adjacent to smooth nonsubmerged titanium implant surfaces,^{23,24} whereas epithelium forms a hemidesmosomal attachment to the implant surface at the ultrastructural level.²⁵⁻²⁷

Unloaded nonsubmerged titanium implants have demonstrated favorable soft tissue healing with resultant structures similar to that around teeth.^{24,28,29} Histometric analyses carried out in these studies indicated similar di-

mensions for implanto-gingival tissues compared to dento-gingival segments.^{30,31} However, these investigations were performed in unloaded implants with short-term healing periods. The purpose of this study was to examine the dimensions and relationships of implanto-gingival tissues surrounding endosseous nonsubmerged one-part titanium implants under unloaded and loaded conditions in the canine mandible over longer periods.

MATERIALS AND METHODS

Implant Design and Surfaces

Two different types of nonsubmerged cylindrical one-part titanium implants[‡] with a hollow-screw design were made from grade-IV commercially pure titanium. The outer diameter was 4.1 mm, and total length was 9 mm. The suprabony, smooth portion of each implant had a machined surface, whereas the intrabony portion was 6 mm in length and had either a titanium plasma-sprayed (TPS) surface[‡] with typical roughness and porosity values of 30 to 50 μm or a sandblasted and HCl/H₂SO₄ acid-etched (SLA) surface with two levels of roughness, one 20 to 40 μm peak to peak, and a superimposed second level at 2 to 4 μm peak to peak.

Animals

Six male, lab-bred American foxhounds were used in this study. At the beginning, these animals were about 2 years old and weighed about 30 to 35 kg. All animals were free of heart worms and were quarantined.

Surgical Procedures: Extraction

Tooth extractions were performed under general anesthesia and sterile conditions in an operating room using 4% thiopental-Na solution I.V. (0.4 ml/kg bw)[§] as a premedication. The dogs were placed on a heating pad, intubated, and inhaled with 1.5–2% isoflurane[#] and monitored with an electrocardiogram. After disinfection of the surgical site with 10% povidone-iodine solution/1% titratable iodine,^{**} 2% lidocaine HCl with epinephrine 1:100,000^{††} was administered by infiltration at the buccal aspect of the lower jaw. Crevicular incisions were made, and all four premolars (P₁-P₄) and the first molar (M₁) were carefully extracted. Prior to extraction, P₂-M₁ were sectioned to avoid tooth fracture. Adaptation of the wound margins was achieved with interrupted sutures. Finally, the remaining teeth were scaled and cleaned.

The day of surgery, the dogs received 20 mg of the analgesic nalbuphine s.c. BID (10 mg/ml).^{‡‡} Three ml of

[‡]Institut Straumann AG, Waldenburg, Switzerland.

[§]Pentothal, Abbott Laboratories, North Chicago, IL.

[#]AErane, Ohmeda Carbide Inc., Liberty Corner, NJ.

^{**}Clinidine, Clinipad Co., Guilford, CT.

^{††}Henry Schein Inc., Port Washington, NY.

^{‡‡}Nubain, Astra Pharmaceutical Products Inc., Westborough, MA.

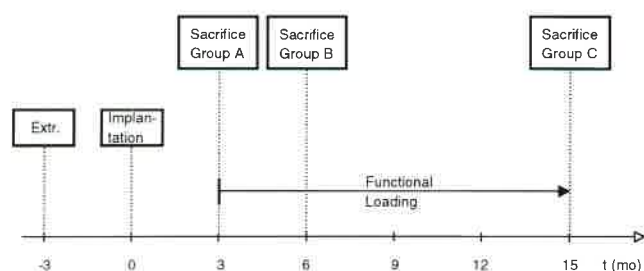


Figure 1. Study design.

the antibiotic benzathine penicillin (150,000 I.U.) with procaine penicillin G (150,000 I.U.) was administered s.c. SID every 48 hours for 7 to 10 days.^{§§} For suture removal, after a period of 7 to 10 days, the animals were briefly anesthetized utilizing a combination (1.1 ml/15 kg bw) of xylazine (7.1 mg/ml),^{|||} acepromazine (2.1 mg/ml),^{¶¶} atropine (0.1 mg/ml),^{***} and ketamine (50.0 mg/ml)^{***} i.v. Prior to suture removal the local wound area was carefully cleaned with 0.12% chlorhexidine digluconate-soaked gauze.^{†††}

Surgical Procedures: Implant Placement

Endosseous, nonsubmerged titanium implants were inserted under the same surgical conditions as the tooth extractions (sterility, operating room, anesthesia) after a healing period of 3 months (Fig. 1). 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. Mental foramina were exposed prior to implant placement. The edentulous osseous ridge was carefully flattened with an acrylic bur and copious irrigation with chilled sterile physiologic saline. Measurements were made using a boley gauge to help distribute 6 test implants on each side of the mandible. Implant osteotomy was performed with torque reduction rotary instruments at 500 rpm using again chilled saline. Dogs were assigned randomly to the three different treatment groups A, B, and C (Fig. 1). According to a randomized starting selection, 3 of each of the test implants were placed in an alternating manner per side and healing screws were placed on top of the implants. In this fashion, no implant type had a biased position in the arch. Due to narrowing of the ridge in the anterior area, 3 of possible 72 implants could not be placed, resulting in a total of 69 inserted implants.

If necessary, periosteal relieving and contouring incisions were made on the buccal and lingual aspects to achieve tension-free wound closure, with a close adapta-

tion of the mucosa to the transmucosal portion of the nonsubmerged implants. Horizontal mattress and interrupted sutures were placed. The day of surgery the dogs received 20 mg of the analgesic nalbuphine s.c. BID (10 mg/ml).^{‡‡} Three ml of the antibiotic benzathine penicillin (150,000 I.U.) with procaine penicillin G (150,000 I.U.) was administered s.c. SID every 48 hours for 14 days; 100 mg of the antibiotic gentamicin was given s.c. on day 1 BID, and the same dosage SID from day 2 through 10 (50 mg/ml).^{†††} To reduce swelling, the dogs received 4 mg of the anti-inflammatory dexamethasone i.m. SID day 1 and day 4.^{§§§} Sutures were removed after 7 to 10 days as described above. A soft diet was utilized throughout the study. 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.

Prosthetic Reconstruction

Four out of the six dogs constituted the loaded implant groups, B and C (Fig. 1). Two months after implant placement in these animals, individual impressions (polyvinyl siloxane) were made^{¶¶¶} and screw-retained gold crowns fabricated (Fig. 4). To imitate the natural dentition of the dogs, the P₁ area had single crowns placed, whereas in the P₂-M₁ area, connected crowns on two implants were made. Octagonal abutments were placed in the implants and precise impressions were taken with standard components including repositional transfer copings.^{¶¶¶} Implant analogs were placed in the impressions and models made for fabrication of the restorations.

Gold copings from the implant manufacturer were incorporated into the wax-ups for the crowns and bridges. The restorations were inserted 3 months after implant placement (Fig. 1). At that time, each bridge was carefully evaluated for passive fit by alternating occlusal screw tightening and evaluating movement of the restoration. In cases where any movement was detected, the bridges were removed and sectioned on the models and placed as separate units to assure passivity of fit. Finally, the restorations were seated using 4 mm occlusal screws and adjusted in the mouth to assure that the crowns were either out of occlusion or had only light contact. Premolars are not in occlusion in the foxhound and the occlusion was maintained as naturally as possible by taking models of the dogs before extraction and duplicating each dog's occlusion. Over time, most dogs exhibited wear patterns on the molar restorations as well as some premolars.

§§Pen-B, Pfizer Inc., Lee's Summit, MO.

|||Miles Inc., Shawnee Mission, KS.

¶¶Burns Veterinary Supply, Oakland, CA.

¶¶Burns Veterinary Supply, Rockville Center, NY.

***Fort Dodge Laboratories Inc., Fort Dodge, IA.

†††Peridex, Procter & Gamble Co., Cincinnati, OH.

‡‡Gentocin, Schering-Plough Animal Health Corp., Kenilworth, NJ.

§§§Dexaject, Burns Veterinary Supply, Oakland, CA.

||||PlakOut Gel, Hawe-Neos AG, Bioggio/TI, Switzerland.

¶¶¶President, Coltène/Whaledent Inc., Mahwah, NJ.

¶¶¶ITI Dental Implant System, Institut Straumann AG, Waldenburg/BL, Switzerland.

Surgical Procedures: Sacrifice

Two dogs (Group A) were sacrificed after a healing period of 3 months and constituted the unloaded implant group (Fig. 1). The other 4 dogs were sacrificed after loading, 2 after 3 months (Group B) and the other 2 after 12 months of loading (Group C). Euthanasia was performed with an overdose of pentobarbital sodium i.v. (0.2 ml = 65 mg/kg bw).**** Mandibles were block-resected with an oscillating autopsy saw^{††††} and the recovered segments with the implants were fixed in 4% formaldehyde/1% CaCl₂ for histologic preparation and analysis.

Histologic Preparation

Each implant with surrounding tissues was prepared for histology as described by Schenk et al.³² Nondecalfied specimens were embedded in methyl-methacrylate and stained with basic fuchsin. Two orofacial sections with a thickness of approximately 80 μm were obtained for Groups A and B and four for Group C.

Histometric Analysis

Histometric quantification was carried out utilizing a high-resolution video camera^{†††††} interfaced to a video monitor.^{§§§§} This optical system was associated with a digitizing pad and a bone morphometry software package with image capturing capabilities.^{¶¶¶¶} All sections were analyzed under several magnifications of light microscopy to locate anatomical reference points. In a few sections in each group of dogs the landmarks were not visible. Therefore, the following numbers of implant sites were evaluated: 76 out of 86 in Group A, 93 out of 96 in Group B, and 172 out of 196 in Group C. The following measurements were taken or calculated (Fig. 2; shown in Figs. 5, 6, 7, and 9).

1. Distance between the gingival margin (GM) and the most coronal point of the junctional epithelium (cJE) = sulcus depth (SD).
2. Distance between cJE and the most apical point of the junctional epithelium (aJE) = junctional epithelium (JE).
3. Distance between aJE and the first bone-to-implant contact (fBIC) = connective tissue contact (CTC).
4. SD + JE + CTC = biologic width (BW).
5. Distance between the bone margin (BM) and fBIC = crestal bone loss (cBL).
6. Distance between the microgap (MG) and the GM.
7. Distance between the MG and cJE.
8. Distance between the MG and aJE.
9. Distance between the MG and fBIC.
10. Distance between the MG and BM.

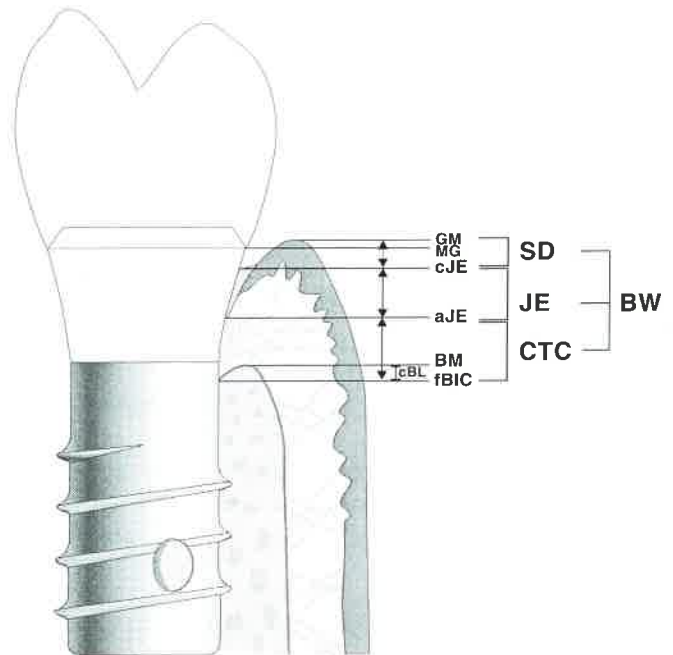


Figure 2. Schematic of histometric evaluation with the following measurements: Distance between the gingival margin (GM) and the most coronal point of the junctional epithelium (cJE) = sulcus depth (SD). Distance between cJE and the most apical point of the junctional epithelium (aJE) = junctional epithelium (JE). Distance between aJE and the first bone-to-implant contact (fBIC) = connective tissue contact (CTC). SD + JE + CTC = biologic width (BW). Distance between the bone margin (BM) and fBIC = crestal bone loss (cBL). Distances between the microgap (MG) and the GM, cJE, aJE, BM, and the fBIC.

Statistical Analysis

Each of the readings for the measurements taken from the orofacial sections were averaged so that each implant had a single value for each measurement. Analysis of variance was done to compare the location of the implant site in the jaws. The location was ordered from most distal to most mesial. Also, Student unpaired *t*-tests were performed to determine any differences between the types of implants. In addition to the measurements indicated in the Histometric Analysis, the proportion of BW attributable to SD, JE, and CTC was also analyzed.

RESULTS

Clinical Findings

Postoperative healing following implant placement was uneventful in all dogs. After 3 months of healing, all 69 implants demonstrated successful tissue integration with ankylotic stability and no clinical signs of peri-implant infection (Fig. 3). No continuous peri-implant radiolucencies were apparent on the radiographs.³³ Therefore, all 48 implants of Groups B and C could be restored with screw-

****Euthanasia-5 Solution, Henry Schein Inc., Port Washington, NY.

††††Stryker Co., Kalamazoo, MI.

†††††CCD-color video camera, Sony Corp., Fujisawa, Japan.

§§§§Hyper HAD video monitor, Sony Corp., Fujisawa, Japan.

¶¶¶¶Bioquant bone morphometry software, R & M, Biometrics Inc., Nashville, TN.



Figure 3. Complication-free healing of four unloaded nonsubmerged 1-part experimental implants (Group A) in the canine mandible. Note small flat-head healing screws in situ.

retained single crowns or fixed partial dentures as described (Fig. 4). After loading, all implants maintained ankylotic stability and a complication-free follow-up.

Histological Findings in Unloaded Implants

The histology around unloaded implants revealed typical epithelial and gingival structures as found around teeth (Fig. 5A, and 6A and 6B). The oral gingival epithelium



Figure 4. Complication-free tissue integration of four loaded nonsubmerged 1-part experimental implants (Group C) in the canine mandible. Note screw-retained single crowns and multiple-unit fixed partial denture in situ.

was keratinized, stratified, and showed rete peg formation. The oral sulcular epithelium was not keratinized, and the JE was tapered to a few cell layers toward the more apical level. Few inflammatory cells and no rete peg formation adjacent to the basal cell layer of the JE were observed confirming the clinical findings. Gingival connective tis-

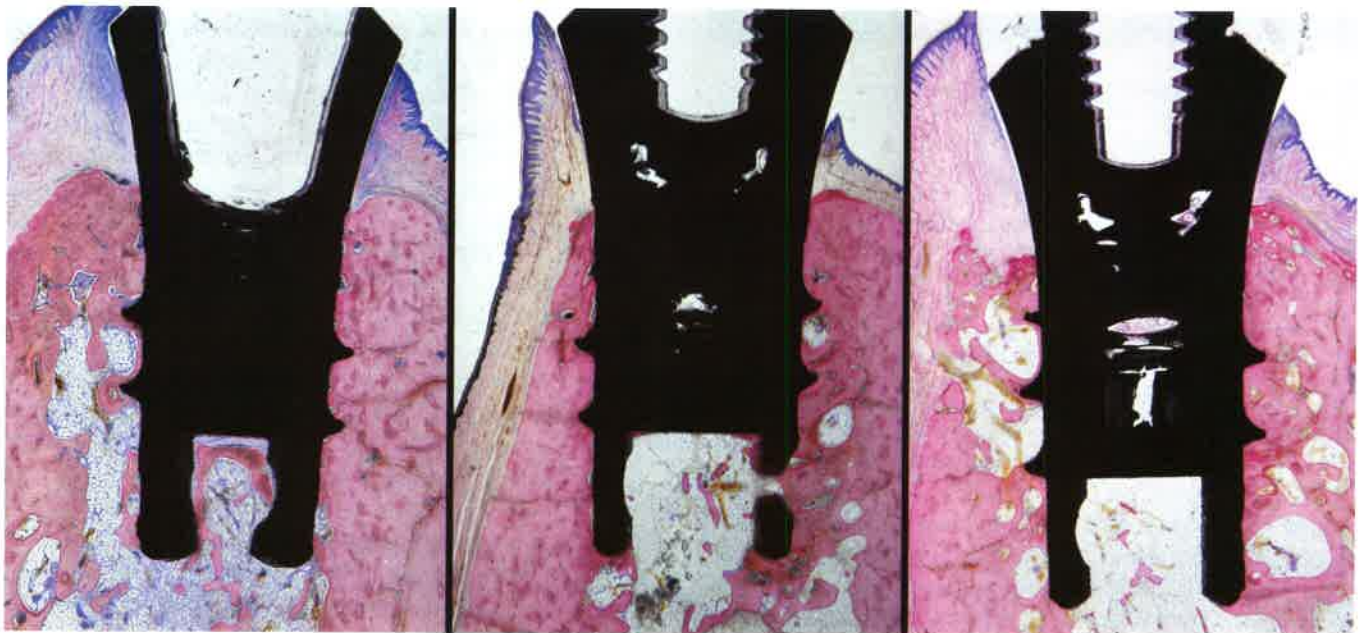


Figure 5A. (left) Bucco-lingual section (basic fuchsin stain; original magnification $\times 3$) of an uneventfully healed nonsubmerged 1-part TPS implant at the early healing stage (3 months unloaded). Note extent of crestal bone loss (cBL) at this early stage. **B** (middle) Bucco-lingual section (basic fuchsin stain; original magnification $\times 3$) of a nonsubmerged 1-part SLA implant showing complication-free tissue integration at the short-term loading stage (3 months loaded). The octagonal abutment^{***} is in situ, whereas the gold crown had to be removed due to processing reasons. Note extent of bone remodeling. Saturated, dark-red stained areas indicate new bone formation especially in the region of former crestal bone loss (cBL). **C** (right) Bucco-lingual section (basic fuchsin stain; original magnification $\times 3$) of an integrated nonsubmerged one-part SLA implant at the longer-term loading stage (12 months loaded). Due to processing reasons, the gold crown had to be removed, whereas the octagonal abutment^{***} is still in situ. Saturated, dark-red stained areas indicate regions of bone remodeling/new bone formation.

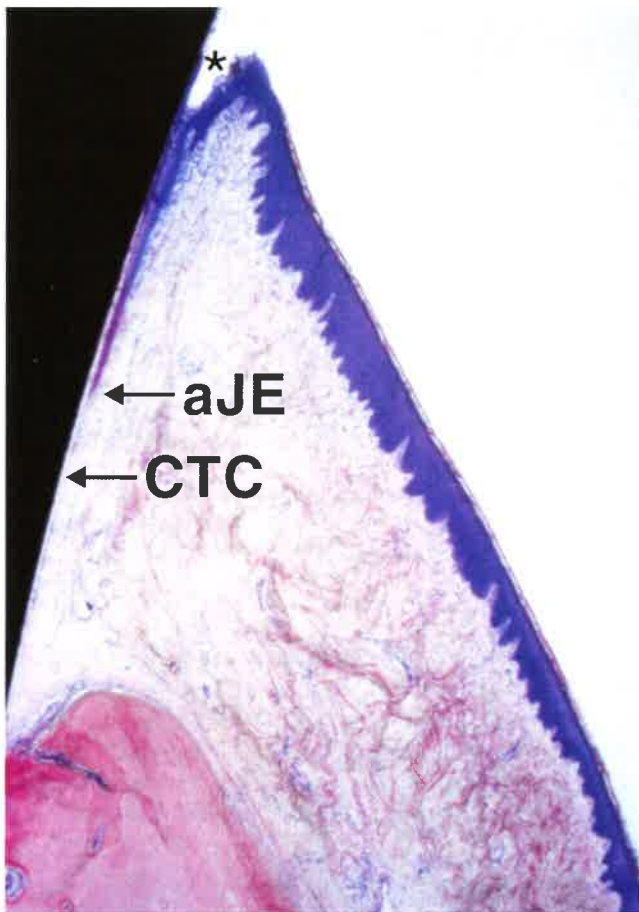


Figure 6A, Bucco-lingual section (basic fuchsin stain; original magnification $\times 12.5$; 1-part SLA implant, 3 months unloaded) showing the gingiva and the most coronal part of alveolar bone. Rete peg formation is only apparent in the area of the keratinized oral gingival epithelium. The oral sulcular epithelium exhibits no keratinization. In the area of the most coronal point of the junctional epithelium (cJE, see *) the soft tissues are slightly torn away (artifact) due to nondecalcified histological processing. The most apical point of the junctional epithelium is indicated (see aJE). No rete peg formation is evident adjacent to the basal cell layer of the junctional epithelium (JE), all showing healthy and physiologic soft tissue structures. In addition, the area of connective tissue contact adjacent to the machined titanium surface is marked (see CTC). A slight round cell infiltrate in the connective tissue is indicating a mild inflammation. Note bone remodeling/new bone formation in the crestal bone region indicated by saturated, dark-red stained areas.

sue always existed below the most apical epithelial cells separating bone from epithelium. In the inner zone adjacent to the relatively smooth, machined implant surface, connective tissue fibers were oriented parallel to the long axis of the implant. In addition, in this area no blood vessels were found showing a scar-like connective tissue contact (CTC). Crestal bone loss (cBL) was evident at this early stage of healing.

Histological Findings in Loaded Implants

The histological findings around loaded implants revealed similar features of the tissues as found in the tissues

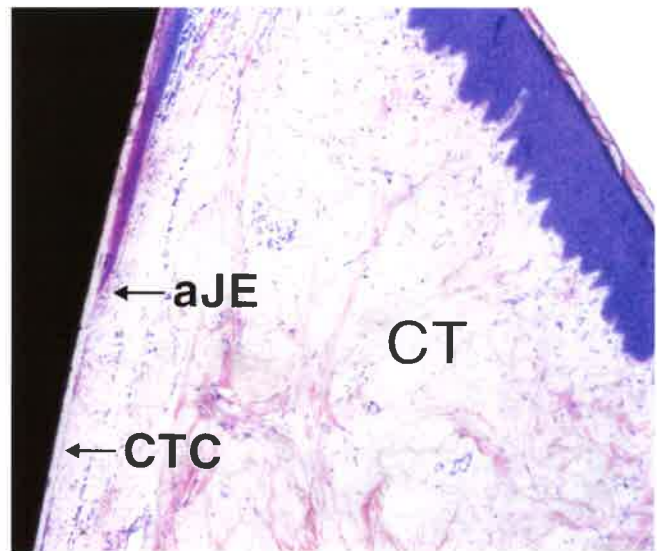


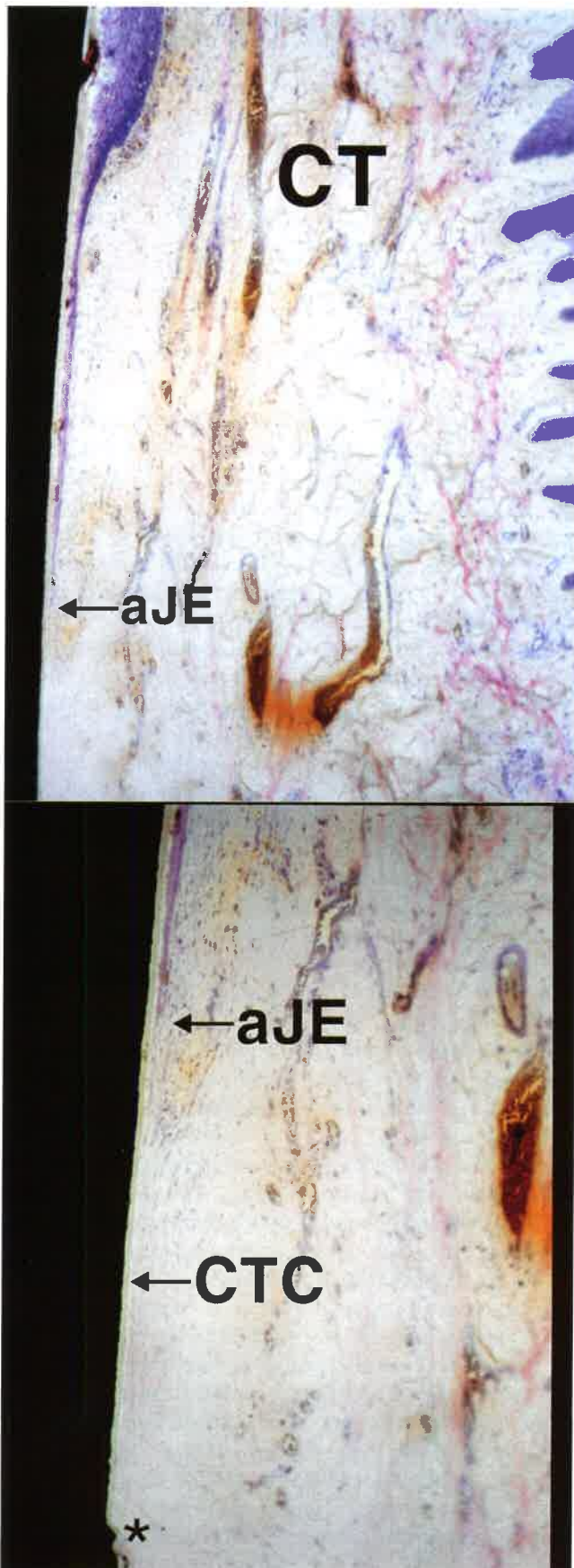
Figure 6B, Same aspect as A at a higher magnification (basic fuchsin stain; original magnification $\times 25$; 1-part SLA implant, 3 months unloaded). The most apical epithelial cell of the junctional epithelium is indicated (see aJE). Note difference between the scar-like connective tissue contact adjacent to the machined titanium surface (see CTC) and the connective tissue supporting the oral epithelium (see CT, as well as Fig. 7B).

around the unloaded implants (Fig. 5B and 5C and 7A and 7B). Minimal inflammatory cells were observed in the connective tissue, and the epithelium revealed structures similar to epithelium around teeth. The presence of the octagonal abutment^{###} and gold crown did not alter the morphology of the soft tissue structures. Thus, a JE was observed that narrowed to a few cells at the apical extent, followed by a zone of connective tissue with typical vascularity. An inner zone of a scar-like CTC was found as described above. Signs of remodeling/new bone formation were evident for both the 3 month and 12 month evaluation. Thus, measurements for cBL decreased after 3 months of loading and were similar at the 12 month time period. A comparison of implants loaded for 3 months (Fig. 5B and 7A and 7B) to implants loaded for 1 year (Fig. 5C) revealed no structural differences within the peri-implant soft tissues.

Soft Tissue Measurements for Groups A, B, and C

The data for Group A implants (3 months unloaded), for Group B (3 months loaded), and Group C implants (12 months loaded) are given in Table 1. The relations of the 3 soft tissue segments to each other forming the BW are shown in Figure 8.

The location of the implant site in the jaws ($P > 0.05$) as well as the implant surface, TPS or the SLA surface, had no significant influence on the assessed parameters ($P > 0.05$). The measurements for MG:fBIC varied among groups. Mean values in Group A for SLA implants



were $2.71 \text{ mm} \pm 0.33 \text{ mm}$ and for TPS implants $3.11 \text{ mm} \pm 0.62 \text{ mm}$, respectively. In Group B SLA implants measured $3.09 \text{ mm} \pm 0.38 \text{ mm}$ and TPS implants $2.73 \text{ mm} \pm 0.53 \text{ mm}$, respectively.

Values for the comparison of the MG:cJE were negative in 8% of the evaluated implant surfaces for Group B implants as well as in 29% of the evaluated implant surfaces for Group C implants indicating the cJE was located coronally to the MG in these instances.

DISCUSSION

Gottlieb³⁴ and Orban and Mueller,³⁵ in initial studies on epithelium, described an attachment of the epithelium to teeth. These studies presented a novel concept of the epithelium that was not universally accepted at that time. Waerhaug,³⁶ in later years, challenged the concept of an epithelial attachment to the teeth but Orban et al.³⁷ in subsequent experiments confirmed an epithelial attachment to teeth with microscopic tissue sections. Later, Sicher³⁸ described a dento-gingival junction around teeth comprised of two parts, attachment of fibrous tissue and attachment of epithelium. Each part was envisioned to serve a separate function. The firmness of the tissue was attributed to the fibrous attachment anchored in cementum and the gingiva. Some fibers were described as circular in form and surrounded the tooth. The epithelium was envisioned as a "cuff" that provided biologic protection to the internal body. This division of function between these tissues was a new concept as previous work had suggested that the firmness of the gingival attachment had been thought to be attributed to the epithelium. Because the majority of implant studies have focused on integration with bone, much less is understood regarding dimensions and relationships of soft tissues around implants.

Figure 7. **A (top)**. Bucco-lingual section (basic fuchsin stain, original magnification $\times 25$, one-part SLA implant, 3 months loaded) exhibiting gingival fiber bundles in the connective tissue (see CT) located between the basal cell layers of the junctional epithelium (JE) on the left side, and the rete pegs of the oral gingival epithelium on the right side. The most apical point of the junctional epithelium is indicated (see aJE). Collagen fiber bundles course in various directions in the described supra-alveolar area. Multiple blood vessels are obvious indicating a copious blood supply. Few inflammatory cells are found. Note gap (artifact) between the machined part of the implant surface and the JE due to nondecalcified histological processing. **B (bottom)**. Same aspect of A at a higher magnification (basic fuchsin stain, original magnification $\times 50$, one-part SLA implant, 3 months loaded). At the top left, adjacent to the junctional epithelium (JE) is visible surrounded by a few inflammatory cells (see aJE). At the lower left, the border between the relatively smooth machined and the rough SLA surface is evident (see *). Note area of connective tissue contact (see CTC) with connective tissue fiber bundles/fibroblasts running parallel to the long axis of the implant between the above mentioned marked two areas. In addition, no blood vessels are apparent in this inner zone indicating a scar-like connective tissue contact (CTC).

Table 1. Measurements for the 3 Different Implant Groups A, B, and C (3 months unloaded, 3 months loaded, 12 months loaded; mean values \pm standard deviation [mm]; n = number of measured implant sites)

Variable(s)	Group A (n)	Group B (n)	Group C (n)
SD	0.49 \pm 0.32 (77)	0.50 \pm 0.30 (93)	0.16 \pm 0.14 (178)
JE	1.16 \pm 0.47 (76)	1.44 \pm 0.41 (93)	1.88 \pm 0.81 (172)
CTC	1.36 \pm 0.64 (80)	1.01 \pm 0.32 (93)	1.05 \pm 0.38 (173)
BW	3.01 \pm 0.74 (76)	2.94 \pm 0.59 (93)	3.08 \pm 0.78 (172)
cBL	0.67 \pm 0.42 (84)	0.43 \pm 0.41 (93)	0.43 \pm 0.66 (178)
MG:GM	-0.09 \pm 0.42 (79)	0.12 \pm 0.69 (93)	-0.08 \pm 0.40 (176)
MG:cJE	0.39 \pm 0.38 (77)	0.48 \pm 0.47 (93)	0.18 \pm 0.44 (176)
MG:aJE	1.52 \pm 0.50 (80)	1.91 \pm 0.51 (93)	1.94 \pm 0.73 (172)
MG:BM	2.23 \pm 0.35 (84)	2.49 \pm 0.57 (93)	2.52 \pm 0.45 (177)
MG:FBIC	2.90 \pm 0.52 (84)	2.91 \pm 0.49 (93)	2.95 \pm 0.68 (177)

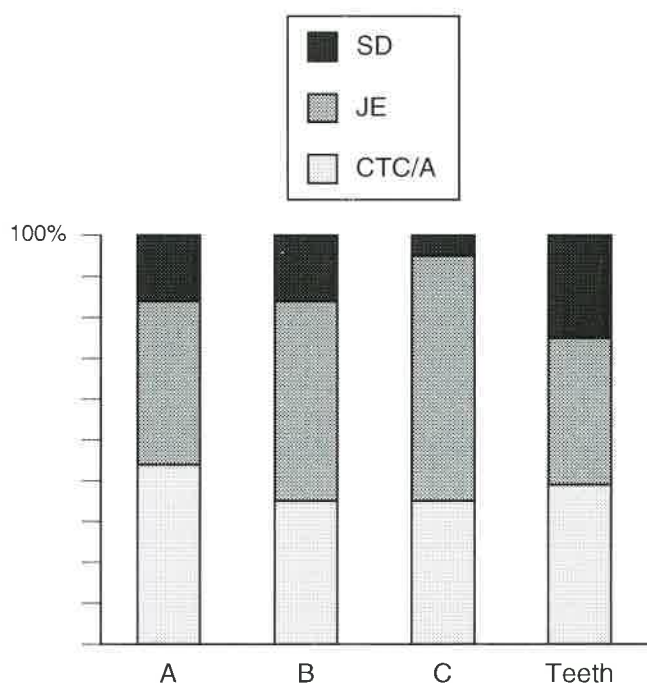


Figure 8. Dimensions of sulcus depth (SD), junctional epithelium (JE), and connective tissue contact (CTC/A) in relation to each other at different time points (Group A = 3 months unloaded, Group B = 3 months loaded, and Group C = 12 months loaded). In comparison to these measurements, the fourth bar shows dimensions and relations of the dento-gingival junction as analyzed in human autopsy specimens.³⁰

As a biologic barrier, it is important to consider the soft tissues surrounding endosseous implants in two aspects, the morphology of the structure and the physiologic function of the implanto-gingival junction. In this study, the dimensions and relationships of the soft tissue segments have been described for healthy endosseous nonsubmerged one-part titanium implants in the canine mandible. Unloaded as well as loaded implants were investigated. The loaded implants were examined at both short-term healing (3 months) and at a longer healing period (12 months). Although the dog only functions in a hinge motion and the premolars are not always in contact, the length of the healing periods should have allowed for any remodeling

of the soft and hard tissues that may have occurred over time. It is significant, therefore, that the dimensions of the implanto-gingival junction remained constant over time and also that their dimensions were similar to the dento-gingival tissues as described by Gargiulo et al. (Fig. 8).³⁰ These findings suggest that the oral soft tissues are dimensionally a physiologically stable structure around 1-part transmucosal structures and that they have a natural relationship to one another. Furthermore, the soft tissues provide a structurally supportive role as gingiva and also provide a biologic barrier for transmucosal structures. These results confirm an earlier paper,³⁹ where the differences between submerged and nonsubmerged implants and the consequences for soft tissue healing patterns by these two approaches were discussed.

Previous studies have examined the ability of epithelium to attach to titanium. In a study by Cochran et al.,⁴⁰ epithelial cell attachment and growth was examined on titanium discs with varying degrees of surface roughness. Following a well described lag period of growth, the epithelial cells proliferated on smooth titanium equally as well as the control tissue culture plastic. Epithelial proliferation did not occur on titanium with a rough surface. These in vitro experiments confirmed earlier in vitro^{26,27} and in vivo²⁵ studies where epithelium was shown to attach to titanium. In one study,²⁶ epithelial cells from porcine periodontal ligament attached to titanium films by a basal lamina and hemidesmosomes. The authors concluded that epithelial cells attach to titanium in vitro the same way epithelium attaches to a tooth surface in vivo.

Buser et al.²⁴ described the connective tissue contact to nonsubmerged titanium implants in beagle dogs. These investigators demonstrated that an approximately 50 μ m to 100 μ m 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. Outside this inner zone, loose connective tissue which encompassed numerous vascular components was found. It was concluded that the zone of CTC adjacent to implants was not similar to the connective tissue attachment

around teeth since inserting perpendicular fibers were not found. These findings were confirmed at the electron microscopic level.⁴¹ The functional difference in the implant connective tissue zone compared to the gingival connective tissue around teeth is, however, unknown.

The findings in the present study support clinical findings of nonsubmerged titanium implants.^{14,24,28,29,42} For instance, in a study of 70 partially edentulous patients with 100 implants, greater than 80% of the sites had a probing depth ≤ 3 mm.¹⁴ The mean probing depth was found to be 2.74 mm and the distance between the MG and the GM was between -3 mm and $+3$ mm. Thus, similar to the mean of the 12-month loaded implants in the present study, implants in the study by Buser et al.¹⁴ had a slightly subgingival implant shoulder. The mean value for the distance MG:GM was -0.12 mm in the human study compared to -0.08 mm for the same distance in Group C implants in the present study. These results are in contrast to findings reported by Apse et al.⁴³ for submerged implants in patients, where mucosal shrinkage was observed around the implant abutment over time as demonstrated by an increased abutment height measurement; i.e., more of the abutment became exposed.

The exact dimensions and relationships of soft tissues around endosseous titanium implants placed in a submerged approach compared to one-part titanium implants inserted according to an intentionally nonsubmerged approach are not known. Evidence suggests, however, that differences exist between these two approaches to implant therapy. Weber et al.²⁹ demonstrated in a canine model using experimental implants that the epithelial attachment was more apical and always located below the microgap in submerged implants compared to nonsubmerged implants. The dimension for mean epithelial attachment was $1.71 \text{ mm} \pm 0.13 \text{ mm}$ for submerged implants compared to $1.18 \text{ mm} \pm 0.27 \text{ mm}$ for nonsubmerged implants. These and other investigators have concluded that the oral epithelium around nonsubmerged implants was similar in appearance to epithelium around teeth.^{4,24,28,29} Indirect evidence on probing and soft tissues around submerged implants with abutments compared to teeth also suggests differences in soft tissues around submerged and nonsubmerged implants. Ericsson and Lindhe,⁴⁴ for instance, demonstrated that under healthy conditions a probe tip penetrates the tissues around submerged implants to within 0.2 mm of the bone crest level while Lang et al.⁴⁵ showed that the probe tip does not penetrate the tissues as far around nonsubmerged implants, stopping at 0.6 mm from the bone crest. Although less force was applied to the probe in the study on nonsubmerged implants (0.2 N vs. 0.5 N), the contribution of the epithelium and the connective tissue resistance to this finding is unknown. Furthermore, in two papers by Berglundh et al.,^{23,46} the dimensions of the soft tissues were greater around submerged implants compared to teeth (see Table 1 in either

paper). This is contrary to the findings presented in this paper where the BW in nonsubmerged implants was similar to the BW in teeth. Thus, the findings by Berglundh et al.^{23,46} and the findings in the present study are consistent with the results of Weber et al.²⁹ discussed above. The material presented by Berglundh et al.^{23,46} revealed a distance between GM and fBIC of 3.17 mm for teeth compared to 3.80 mm for submerged implants. Similarly, the distance from the GM to the aJE was 2.05 mm for teeth compared to 2.14 mm for submerged implants. Thus, the epithelium appears to migrate further apically around submerged implants as shown by Berglundh et al.^{23,46} and Weber et al.²⁹

Evaluating radiographic and clinical data also suggests that epithelium migrates below the implant-abutment junction (microgap) in initially submerged implants. Several longitudinal radiographic studies indicate that crestal bone loss around smooth submerged titanium implants is around 0.9 mm to 1.6 mm over the first year of loading. After the first year, an annual crestal bone loss of approximately 0.05 mm to 0.13 mm occurs.^{5,10,12,19,21,47-51} These findings are so consistent that measurements of 1.5 mm and less for the first year and less than 0.2 mm for every following year have been suggested as criteria of success for endosseous implants in general.^{52,53} It should be noted, however, based upon the findings reported in this paper and the discussion above that these measurements may only be appropriate for submerged smooth titanium screws. It is proposed based upon the soft tissue findings around nonsubmerged 1-part implants, that these measurements may not be appropriate for all titanium endosseous implants, and in particular, nonsubmerged 1-part titanium implants with rough surfaces in areas of osseous integration and smooth surfaces in areas of connective tissue and epithelial integration. As of today, it is clear from many *in vitro* as well as *in vivo* studies that bone apposition is greater adjacent to rough surfaced implants compared to implants with a smooth surface.⁵⁴⁻⁶⁸ Berglundh et al.²³ concluded that "... at both tooth and implant sites the apical cells of the junctional epithelium terminated approximately 1.0 mm to 1.5 mm coronal to the alveolar bone crest. . . ." Given the radiographic data indicating 1.5 mm of bone loss around the smooth titanium screw (submerged approach), this places the epithelium consistently below the microgap as reported by Weber et al.²⁹ using submerged experimental implants. This finding has recently been confirmed using beagle dogs and loaded submerged machined screw implants placed in a two-stage approach.⁶⁹ The authors found "... the junctional epithelium extended a short distance apical to the implant rim. . . ." The relevance of the soft tissue differences between submerged and nonsubmerged implants is not known but may impact on the long-term maintenance of the implants and the health of the peri-implant tissues. Many papers document long-term success of both

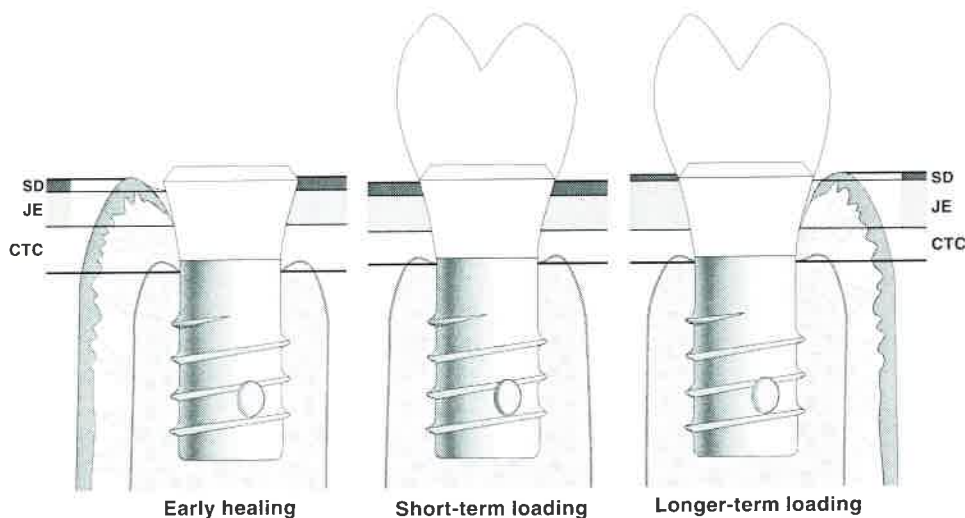


Figure 9. Model of peri-implant soft tissue integration. Note constant value for biologic width (BW) over time.

approaches to endosseous implant dentistry. However, it is not possible to determine morphology of the soft tissues and effectiveness of the implanto-gingival barrier under clinical inspection.

In the canine model used in this study where the tissues were cleaned 3 times per week, there was no significant difference between unloaded and loaded implants as regards the overall dimensions of the implanto-gingival soft tissues. This would suggest that the tissues, once healed, reach a level of maturity that does not change significantly over time unless an environmental change occurs such as inflammation, toothbrush trauma, etc. This appears to be the case with dento-gingival soft tissue and the present data support such a concept around healthy nonsubmerged 1-part implants. It is unknown if the implanto-gingival soft tissues will serve as a barrier similar to dento-gingival soft tissues due to the morphological differences in these two situations. Periodontal ligament fibers are found apical to the dento-gingival connective tissues, whereas bone is present in the implanto-gingival case. The data support the fact that the dimensions of the tissues are physiologically stable for periods greater than one year and thus may be stable during longer maintenance periods. The oral hygiene performed in this study included both chemical (chlorhexidine-digluconate[®]) and mechanical (soft toothbrush plus soft sponge) therapy. The data demonstrate for the first time that routine mechanical and chemical therapy for up to 15 months will not significantly alter, at the histological level, the soft tissue dimensions around healthy integrated nonsubmerged 1-part titanium implants.

A model of peri-implant soft tissue integration for endosseous nonsubmerged titanium implants is shown in Figure 9. The findings reported in this study permit a concept that the BW is physiologically constant for 1-part

oral transmucosal structures including teeth and nonsubmerged implants. These implants represented early stages of healing; i.e., from time of implant placement until time of loading (3 months unloaded), short-term loaded (3 months loaded and 6 months healed) and longer-term loaded (12 months loaded and 15 months healed) implants. As in the case of teeth, the CTC in nonsubmerged implants remains relatively stable, while the soft tissue differences that occurred largely took place in the dimension of the JE and the SD. These data therefore suggest that perturbation of the oral soft tissues with the placement of a nonsubmerged 1-part implant results in a healing process such that the connective tissue is formed and matures to a state similar to surrounding tissues and that the JE and SD are adaptable with their dimensions being dynamic with time of healing. These findings are supported by the fact that implants with two different rough endosseous surfaces were examined in this study and that no significant differences were found concerning the BW when comparing the two surfaces. Furthermore, no differences were found in soft tissue dimensions comparing implant sites in the more posterior area of the mandible versus the more anterior sites in spite of a more narrow alveolar ridge in the anterior implant sites.

Conclusion

This study indicates that the dimensions and relationships of the implanto-gingival junction of healthy nonsubmerged 1-part titanium implants are similar to dento-gingival tissues. Thus, both junctions have relative physiologic dimensions. The measurements of the tissues were similar under unloaded and loaded conditions. Routine maintenance therapy including mechanical and chemical treatment for up to 15 months did not alter the overall dimensions of the soft tissues. These data suggest that a

biologic width exists around nonsubmerged 1-part titanium implants as well as around teeth and that this is a physiologically formed and stable structure at least in the case of nonsubmerged titanium implants.

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