Histologic Evaluation of the Periodontium of Abutment Teeth in Combination Implant/Tooth Fixed Partial Denture

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The histologic response of the periodontal tissues of teeth rigidly joined to implants with a fixed partial denture was evaluated using light microscopy. The fourth premolar of a dog was connected to implants placed in the first and second premolar position with a fixed partial denture. The restored teeth were under function for periods of 6, 12, 18, and 24 months, with unrestored fourth premolars as controls. The histology of the periodontal ligament on the fourth premolar was found to be similar in the control and the restored teeth. The periodontal tissues contained a minimal amount of inflammatory cell infiltrate. The crestal bone was cortical in nature, showing no periodontal breakdown. The orientation of the periodontal fibers was easily determined, indicating that minimal remodeling had taken place. The number and morphology of the blood vessels were also similar in the control and the treated teeth. The lack of inflammation and stability of the periodontal tissue suggested that the use of combination implant-to-natural-teeth restorations with rigid joints in this animal model does not result in deleterious effects on the periodontal tissues and that the forces placed on the tissues are within the remodeling capabilities of the teeth.

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Key words: cementum, dental implants, intrusion, light microscopy, osseointegration, periodontal ligament

Implant therapy has expanded to include the restoration of the partially edentulous patient. Often the only prosthetic alternative to a distal extension removable partial denture in the partially edentulous patient is an implant-supported prosthesis with a single implant abutment. A single implant can serve as an abutment for several types of restorations, including a single-tooth implant restoration, a fixed partial denture that is a cantilever restoration, or a combination implant/natural tooth restoration. The use of cantilevered pontics supported by natural teeth as abutments in posterior areas is contraindicated because of the magnitude and axial duration of the occlusal forces that are placed on the restoration's pontic. Such occlusal forces can result in dislodgment or fracture of the restoration, fracture of the abutment tooth, or trauma from occlusion on the abutment tooth. The forces of occlusion can be destructive to any type of restoration, whether it involves teeth or implants.[1]

The use of implant/tooth combination restorations began in the mid-1980s.[2–4] Various authors have debated the effectiveness of prostheses supported by a combination of implants and natural teeth.[5,6] Teeth with an intact periodontal ligament

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have normal mobility (between 50 and 200 µm). Implants, on the other hand, have a flexure of less than 10 µm, which is the flexure of bone.[7] These inherent differences in the mobility of the abutments are a major dilemma for the design and fabrication of a prosthesis. The prosthesis must not only restore function but also preserve the support of both the implant and the natural tooth that serves as an abutment.

The combination implant/tooth fixed partial denture has several biomechanical considerations. If the tooth is not occlusally loaded vertically, the stress placed on the implant might lead to its failure. Failure can involve the mechanical portion of the abutment, such as implant fracture and loosening or breaking of screws. The loss of integration of the implant itself is also possible.[8]

Biomechanically, the tooth can be affected by the forces of occlusion, intruding the tooth under the restoration. Various theories have been presented as to why teeth intrude in the combination implant/tooth fixed partial denture. These include disuse atrophy, harmonic resonance, mandibular flexion and torsion, flexion of the fixed partial denture metal framework, impaired rebound memory, debris impaction, or microjamming and the ratchet effect.[3,6,9–12] The clinical consensus on the use of combination implant/natural tooth fixed partial dentures is that they should be avoided with the use of 2 implants in the edentulous space.[11,12] When this is not practical or possible, rigid fixation to 1 abutment tooth should be carried out.[3,6,10–12]

Forces placed on teeth are absorbed largely by displacement of blood and extracellular fluids to nonloading regions of the ligament and through foramina in the alveolar bone. Depending on the intensity and duration of the force applied, varying distortion of the alveolar bone occurs.[13,14] If there is excessive force placed on the teeth (ie, hyperfunction), the result is a breakdown of the periodontal tissue. Carranza described 3 stages of periodontal modification related to hyperfunction.[15] In stage I, excessive pressure on the periodontal ligament on one side of the tooth results in a resorption of the alveolar bone on that side of the tooth that corresponds to the direction of the force. On the opposite side of the tooth, tension is placed on the periodontal ligament. The fibers elongate and stimulate apposition of highly trabeculated alveolar bone.[13] Histologically, osteoid bordered by osteoclasts and incremental lines of bone formation can be observed. In stage II, the damaged tissue is repaired and remodeled, and new connective tissue cells, fibers, bone, and cementum are formed. As long as the repair stage can keep up with the injury stage, the periodontium is continually remodeled (stage III). Elimination of the excessive forces is achieved with the removal of the force or the tooth orthodontically moving out of the way of the force.[16] If the teeth continue to undergo hyperfunction, with the repair stage unable to keep up with the injury stage, there is derangement of normal ligament architecture, which leads to frank necrosis. There can be a 50% increase in the width of the periodontal ligament space.[13,17–19] The effect of hyperfunction on periodontal tissues results in a decrease in the width of the periodontal ligament space in nonfunctioning teeth and a total loss of functional orientation of the fiber bundles.[20]

The periodontal ligaments of fourth premolars of 30 mixed-breed dogs were examined. The groups involved untreated control and treated teeth. Both the control and the treated teeth were fourth premolars. Treated teeth were those serving as abutments for fixed partial dentures in combination with implants. The control teeth were not restored. Treated premolar teeth were available for analysis after the fixed partial dentures were loaded for 6, 12, 18, and 24 months. The control teeth were unrestored fourth premolars obtained from animals euthanized at 5 months postimplantation.

The purpose of this paper was to present the evaluation of the histologic response of the periodontal tissues of a tooth that was an abutment for a combination implant/natural tooth fixed partial denture. The abutment for a combination implant/natural tooth fixed partial denture was compared to the periodontal tissues that supported a similar tooth but were not splinted to an implant. Analysis of the periodontal tissues was accomplished using light microscopy. The specific aims of this study were to describe the histologic characteristics of the periodontal ligament and the bone adjacent to mandibular fourth premolars in dogs and to describe the blood vessels contained in the periodontal ligament.

Materials and Methods

The samples for this study were obtained from an overall experimental investigation concerning the tissue response to various types of dental implants using 30 mongrel dogs weighing 20 to 25 kg each (*Canis familiaris*). The main disadvantage of the use of the dog model is the possibility of differences in the healing, loading, and occlusal response between humans and dogs.[21]

After bilateral extraction of the mesial 3 premolars, 120 endosteal dental implants were placed bilaterally.[22] The 120 implants were evenly divided into 1- and 2-stage systems and included ceramic and titanium cylindric root-form implants and titanium blade implants; 96 of the implants were restored in combination with natural teeth. Control teeth were obtained from animals unrestored with implants and the animals were euthanized 5 months after implant placement. The experimental animals with restored implants were euthanized at 6 months, 12 months, 18 months, and 24 months after cementation of the final prosthesis (Fig 1).

Surgical Procedures. The animals were anesthetized with pentobarbital followed by endotracheal intubation and halothane/oxygen inhalation anesthesia. The mandibular first, second, and third premolars were extracted bilaterally under aseptic conditions. Alveoloplasty was performed to flatten the superior portion of the ridge. Following irrigation with sterile saline, the mucoperiosteal flaps were closed with resorbable gut suture and postoperative radiographs were obtained.

After a 2-month healing period, each animal was returned to the surgical suite, anesthetized, and prepared for implant placement. With bone drills and taps supplied by the manufacturer, the bone was prepared following the manufacturers' recommended protocol. Careful surgery is important, since low instrument speed is one way of ensuring that the bone will not be overheated during drilling.[23] The implants were placed according to manufacturers' recommendations. The implants were left unloaded during a 3-month healing period before prosthodontic procedures were accomplished.

Prosthodontic Procedures. A suitable abutment to be used for fixed prosthodontic restoration was selected for all animals. Rexillium alloy fixed prostheses involving 96 of the 120 endosteal implants and 48 natural mandibular premolar teeth were involved in standardized prosthesis fabrication. The remaining 12 unrestored mandibular premolars served as controls.

For placement of the implant and the taking of impressions, each animal was returned to the surgical suite. The animals were anesthetized and prepared in the same manner as for tooth extraction and implant placement. A double thickness of softened baseplate wax was adapted to the appropriate arch. The wax was then covered with autopolymerizing acrylic resin (DeTrey Special Tray, DeTrey Division, Dentsply Limited, Weybridge, Surrey, England) and shaped to conform to the arch. After setting, the custom tray was removed and the wax was discarded. A handle was added, the tray was trimmed to final form, and the appropriate impression adhesive was applied to the tray. After several custom trays were made for several animals, a set of trays in assorted shapes and sizes had been produced that served the remaining animals. For consistency, the fixed abutment heads, instead of the transfer pins supplied by the manufacturer, were used in the impression-taking procedure.

A procedure analogous to that performed in humans was used to make modified $\frac{3}{4}$ crown preparations on the mandibular fourth premolar, using a water-cooled high-speed handpiece and diamond burs. The large size of these teeth made it possible to keep all margins supragingival. Preparations on the teeth were made parallel to the long axis of the implants. Impressions were made with Surgident Neo-Plex polysulfide base impression material (Columbus Dental, St. Louis, MO). Polysulfide impression material was used because it has good tear strength and is inexpensive and flexible. Flexibility and tear strength was important because the long canine teeth tended to fracture when removed from the impression material.

Impressions were poured with Duralay resin (Reliance Dental Manufacturing, Worth, IL) retained with die pins in the canine regions. The implant analogues were supplied by the manufacturer and the fixed abutment heads were placed in the appropriate impression sites and secured with sticky wax. Silky Rock Die Stone (Whip Mix, Louisville, KY) was poured to complete the casts. When set, the casts, including the margins, were trimmed and 4 layers of die spacer (American Dental Supply, Easton, PA) were placed over the molar preparations and implants.

The casts were hand-articulated and the coping and fixed units were waxed and cast with Rexillium III alloy (Jeneric/Petrition, Wallingford, CT). The steep vertical overlap of dog teeth and primarily vertical chewing stroke made jaw relation records and articulator mountings unnecessary. The occlusion on the casting was adjusted and the casting was polished.

Prosthesis fabrication was completed 2 months after the final impressions were made. For cementation of the completed prostheses, the animals were returned to the surgical unit and anesthetized. The endotracheal tube used for the procedure had been specifically modified by a veterinarian. The modification allowed the anesthesia unit to be disconnected during the brief period of time during which the animal's jaw was closed to verify and adjust the occlusion. Panavia cement (J.B. Morita USA, Tustin, CA) was selected for cementation. After the cement set, the margins were cleansed and irrigated, the occlusion was verified, and the animals were released to the care of the veterinarian for recovery (Fig 2).

Clinical Evaluation and Follow-up. The animals were evaluated at monthly intervals. A maximum follow-up period of 2 years was designated before the study was initiated. A random-sequential selection of the animals to be euthanized at 5 months after implant placement and 6 months, 12 months, 18 months, and 24 months after prosthesis attachment was also designated at the beginning of the study. There were no failures of any of the prostheses. Periodontal evaluations were made of the teeth and the implants at 1, 3, 6, 9, 12, 15, 18, and 24 months (Fig 1).

Perfusion and Fixation Procedures. At the time scheduled for euthanasia, the animals were sedated as already described and radiographs were obtained. The common carotid arteries were cannulated through a small incision in each artery. The animals were euthanized with simultaneous overdoses of pentobarbital (325 mg/mL) injected intravenously and potassium chloride injected intracardially.

The fixation process was completed with perfusion of 1 liter of heparinized (1000 units/L) saline initially administered by peristaltic pump. When perfusion was initiated, the previously tagged external jugular veins were severed to allow escape of the perfusate and blood. Heparinized saline was perfused through the vasculature until the exiting perfusate was clear. Subsequently, 3% phosphate-buffered glutaraldehyde was administered over a 45-minute period.

Segments of each jaw containing implants, teeth of importance, and surrounding bone and soft tissue were retrieved using a Stryker bone saw (Stryker, Kalamazoo, MI) and placed in 10% neutral buffered formalin for immersion fixation. A Gillings-Hamco thin sectioning saw (Itamco Machines, Rochester, NY) was used to reduce the size of each specimen.

Histologic Preparation. According to the technique described by Steflik et al, samples were embedded in clear polymethyl methacrylate resin (PMMA).[24,25] The PMMA blocks were then serially sectioned with a Buehler Isomet low-speed saw (Buehler, Lake Bluff, IL) to provide buccolingual sections of the teeth at various locations along their long axis. For each tooth, 20 to 35 sections were retrieved. The longest section through each root of the tooth was used for morphometric analysis in this study (the mandibular fourth premolar of a dog has 2 roots).

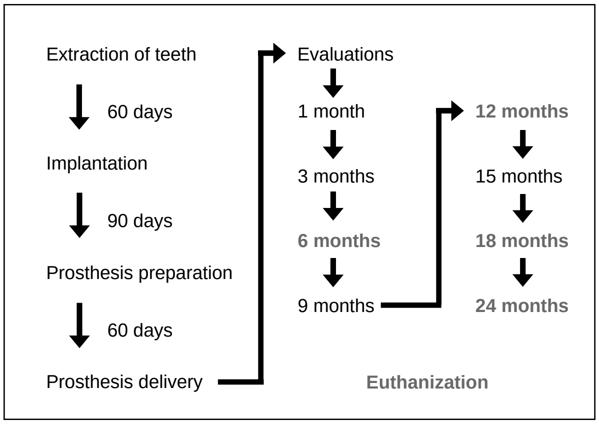

Fig 1 Timeline indicating when dogs were treated, evaluated, and euthanized.

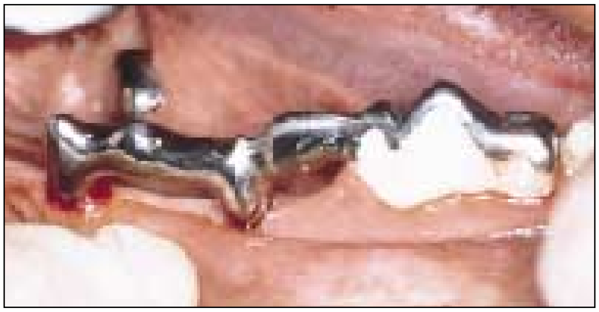

Fig 2 Clinical photograph of a cemented combination implant-to-tooth fixed partial denture in the premolar region of the dog's mandible.

The sections were stained for light microscopic examination with warmed Paragon 1301 stain as described by Steflik.[25] This technique allowed for visualization of the entire specimen and the tooth, with clear distinctions between teeth, bone, connective tissue, epithelium, and periodontal ligaments.[14,24,26]

The longest section through the center of each tooth root was analyzed under the light microscope using an Olympus BH2 light microscope (Olympus America, Melville, NY) with an MTV-3 video adapter (Olympus America) for a MTI 65 video camera (Dage-MTI, Michigan City, IN). The light microscopic analysis was used to determine the histology of the periodontal ligament space and evaluation of the blood vessels.

Results

Initial reports from the overall initial investigation indicated that all animals tolerated the surgical and prosthetic procedures well. All implants were evaluated clinically and histologically and determined to be osseointegrated.[24,26–38] There were no signs of inflammation or infection in the treated areas. Periodontal evaluation of the teeth and radiographic evaluation of the bone revealed that they were healthy and within the normal limits of what could be expected around the teeth of the animals.[38] None of the problems referred to in the literature, such as breaking of screws, dislodgment of the fixed partial denture, or intrusion of the natural teeth, were noted.[24,26,29,31–36,38]

The histology of the sections obtained from each evaluation period was very similar to that of the control teeth. Throughout the periodontal ligament, fibers and material consistent with extracellular matrix, vessels, and nerves were observed. The cells found in the periodontal ligament were fibroblasts, cementoblasts, osteoblasts, osteoclasts, epithelial remnants, nerve cells, and inflammatory cells. Each of these will be described as they appear in the various photomicrographs.

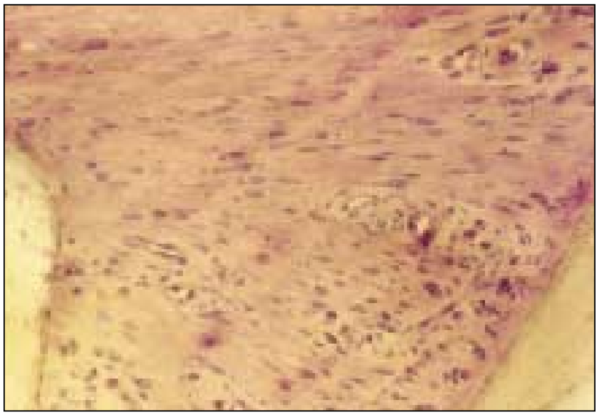

Fig 3 Photomicrograph of the periodontal ligament at the crest of the alveolar bone *(left)* and the attached fascicles of fibers supporting fibroblasts inserting into the cementum on the right. Zones of loose fibrous connective tissue supporting blood vessels are also visible (Paragon stain; original magnification ×250).

All the specimens prepared for light microscopic analysis revealed healthy soft tissue around the teeth. There was a minimal amount of inflammatory cell infiltrate in the periodontal tissues. The crestal bone was cortical in nature. None of the crestal bone showed any periodontal breakdown. The orientation of the fibers of the periodontal ligament was highly organized within each group of fibers and blended with the neighboring fibers coronally and apically. Fibroblasts were normally oriented parallel to the periodontal ligament and were pleomorphic in shape. Multiple blood vessels were observed between fiber bundles (Fig 3). The fibers of the periodontal ligament were oriented obliquely in the mid-root area (Fig 4). Multiple blood vessels were observed between the fiber bundles (Fig 4b).

Cementoblasts were found adjacent to the surface of the cementum. Similarly, osteoblasts were found adjacent to the surface of the alveolar bone, lining the periodontal ligament. Cementoblasts and osteoblasts had a strongly stained, basophilic cytoplasm. Large multinucleated osteoclast cells were present within resorption (Howship's) lacunae at the bone surface. The alveolar bone was highly organized with the development of Volkmann's canals and Howship's lacunae (Fig 4).The periodontal ligament is a highly innervated struc-

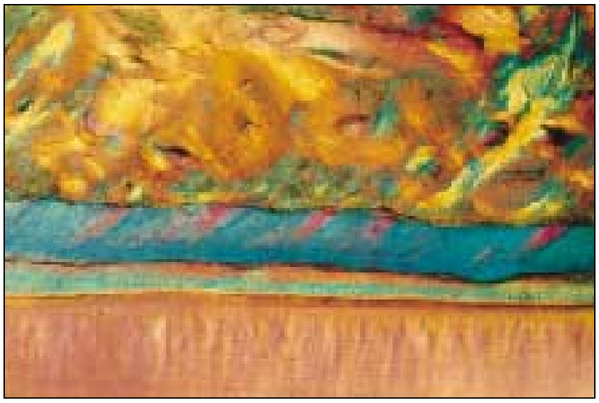

Fig 4a Photomicrograph of the alveolar bone *(top)* adjacent to the periodontal ligament using Nomarski differential interference microscopy. The dentin *(bottom)* and the adjacent cementum are easily differentiated (Paragon stain; original magnification ×60).

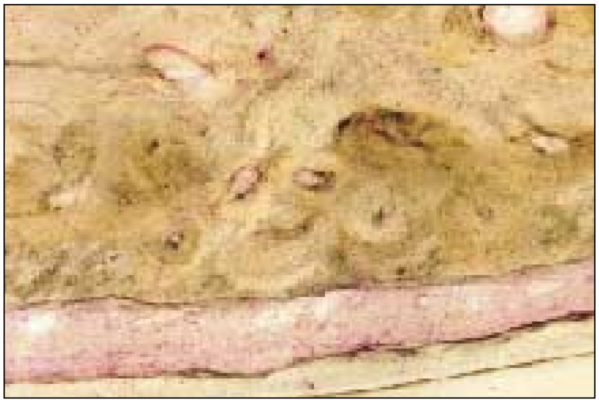

Fig 4b Photomicrograph of the periodontal tissues in the midroot area of the dog's tooth showing fibrous connective tissue supporting a number of vascular elements (Paragon stain; original magnification ×60).

ture. Nerve tissue was found throughout the periodontal ligament, often grouped with 2 other blood vessels (Fig 5). The inferior alveolar nerve's large size indicated the high degree of innervation that occurred with the teeth and their surrounding tissues (Fig 6).

Evaluation of the vasculature of the periodontal ligament that supported control and experimental teeth was accomplished qualitatively. The periodontal ligament was highly vascular, and capillaries were observed throughout the periodontal ligament space (Fig 5). The number of vessels in the periodontal ligament of the loaded teeth was consistent with control teeth throughout the various evaluation periods. Capillaries were seen in all the surrounding tissues of the periodontal ligament. (Figs 3, 4, and 6). Blood vessels found in the periodontal ligament were differentiated as either arterioles or venules and, at higher magnification, capillaries. In general, arteries and veins were seen together with a nerve (Fig 5).

Discussion

Previous studies have only speculated on the effect of joining a tooth rigidly to an implant with a fixed partial denture.[6,10] Furthermore, the histologic response of the periodontal tissues of natural teeth that serve as abutments for fixed partial dentures has not been reported in the literature. The data presented here evaluated the periodontal tissues of abutment teeth after functional loading with an implant/tooth fixed partial denture for up to 24 months.

Although the histologic response of the alveolar bone and connective tissue attachment levels following placement of a fixed partial denture on natural teeth has not been described previously, the response of the marginal gingival tissue of restored teeth has been reported. The placement of fixed partial dentures with natural teeth as abutments has no deleterious effect on the periodontal tissues when the restoration is properly designed. The proper design and fabrication of the fixed partial denture requires optimal placement of restorative margins, good axial contours and embrasures, and optimal occlusion.[39–43]

The advent of osseointegrated implants has resulted in the desire to restore patients without the use of removable prostheses. To overcome the engineering shortcomings of single-tooth implant systems, the combination implant/tooth restoration has been suggested. The effect of attaching an immobile implant to a tooth that has a periodontal ligament that permits adaptive movement is uncertain. Debate has been stimulated as to whether a rigid or nonrigid connection between the implant and the abutment teeth is needed.[17,40,44–47]

To determine the effects on the periodontal tissues of splinting a natural tooth to an implant, 30 dogs received combination implant/natural tooth restorations. The periodontal ligament of a fourth premolar of a dog was examined as a control. Canine premolars differ slightly from human premolars, since canine premolars do not have flat surfaces that occlude.[48] Also, during closure there is sliding contact between opposing premolars that permits a shearing and slicing of meat.[21] There-

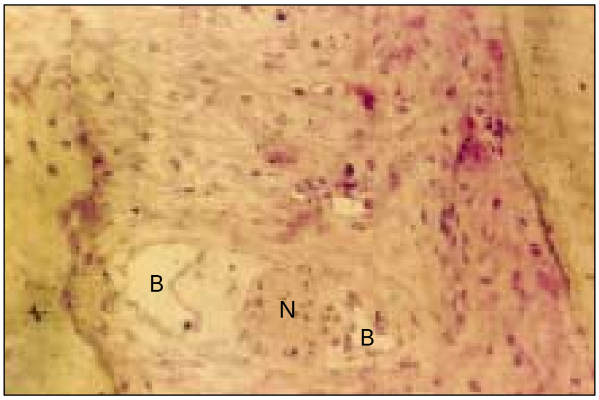

Fig 5 Photomicrograph of 2 blood vessels (B) on either side of a nerve (N) in the periodontal ligament (Paragon stain; original magnification ×500).

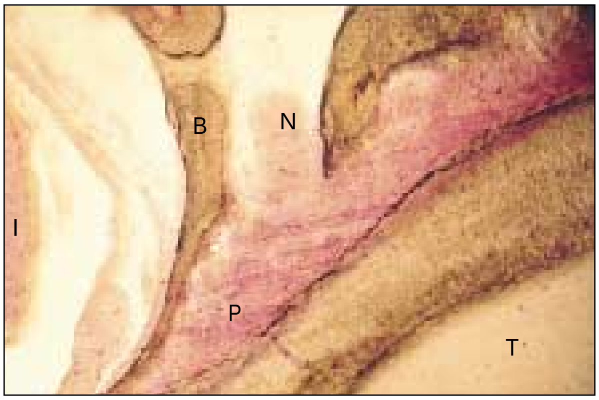

Fig 6 Photomicrograph of a nerve (N) between the trabecular bone (B) and adjacent to the periodontal ligament (P). The large inferior alveolar nerve (I) is to the left. The smaller nerve (N) courses between the periodontal ligament and the trabecular bone adjacent to the tooth (T) (Paragon stain; original magnification ×125).

fore, most of the forces placed on the premolars were in a lingual direction. Therefore, to determine effects on functioning, supporting tissue, sections for this study were made of the teeth in a longitudinal, buccolingual direction. An advantage of the dog model was that the remodeling of this bone occurred 50% faster than in humans and provided for ideal healing times.[49,50] By waiting 5 months before loading the implants, the investigator could verify whether the implants were fully integrated or rejected.[49,50] Of particular interest for this investigation was that no intrusion or increase in mobility was noted for any abutment teeth. The lack of intrusion was possibly the result of the passive nature of the cemented fixed partial denture. Several layers of die spacer were placed on the dies to allow for a passive seating of the fixed partial denture on the teeth and the implant abutments. The cement in the fixed partial denture compensated for any discrepancy that may have occurred in the fabrication of the prosthesis. The lack of pathology noted on all the samples over the 24-month period indicates that all the forces placed on the teeth were within the adaptive capabilities of the teeth. All the fixed partial dentures were retrieved at the time of tissue processing.

The histologic appearance of the dogs' periodontal tissues, as presented in this study, was consistent with results found in other studies.[14,18,19,51,52] The blood vessels in the periodontal ligament could be easily identified as either arterioles or venules and at higher magnification as capillaries. Most of the time the arteries and veins were seen together in the bone and the periodontal ligament. This was similar to what has been reported by Biancu[51] and Biancu et al.[52] The number and size of the blood vessels were used as qualitative criteria to determine if there was any adverse effect on the periodontal tissues. Samples of the periodontal tissues obtained at different time periods and from different zones were compared with respect to qualitative assessment of blood vessel morphology and general amounts of vessels. However, quantitative assessment of the blood vessels was deemed outside the scope of this current investigation. Interestingly, Carranza reported that there was an increase in the number of blood vessels during any time the tooth was placed under an excessive functional load.[15] The evaluation of the blood vessels for the samples examined in this study showed little change during the evaluation period. The number and morphology of the blood vessels appeared consistent with that of a periodontal ligament of normal appearance. This indicated that the tooth was undergoing no adverse effects as a result of the restorations.

The findings of this study imply that the forces placed on the abutment tooth in a combination implant/tooth fixed partial denture in this model system can be within the adaptive capabilities of the tooth's periodontium. The use of cemented retainers on abutments of different mobilities is not contraindicated. In fact, over the long term, the tooth may even have reduced mobility when combined as a terminal abutment with an implant in a combination implant/tooth fixed partial denture. The situation presented in this study was a worst-case scenario. Shillingburg et al stressed the need to avoid the use of distal extension cantilevers and emphasized that the greatest forces of occlusion were closer to the hinge of the condyle in the fossa.[1] The lack of intrusion on the fourth premolar in this situation indicates that with careful management of the occlusion, teeth and implants can be used in combination restorations with a rigid connector between the abutments in this model.

Conclusions

Observations of the vasculature and morphology indicated stability and lack of inflammatory reaction of the periodontal ligament of the tooth connected with a rigid joint in combination implant/natural tooth fixed partial dentures. When restored with this type of fixed partial denture, the teeth undergo a period of adaptation. The natural-tooth abutments need to be properly restored such that the forces placed on the abutments are of a small enough magnitude that the force is within the adaptive capacity of the periodontal tissues in this animal model. The lack of intrusion on the dogs' fourth premolar in this situation indicates that with careful management of the occlusion, teeth and implants can be used in combination restorations with a rigid connector between the abutments.

Acknowledgments

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