The Effect of a Constant Electrical Field on Osseointegration after Immediate Implantation in Dog Mandibles: A Preliminary Study

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Purpose: The long time span between insertion of implants and functional rehabilitation often inconveniences patients. Accelerating bone growth around dental implants can shorten this time span. This in vivo study evaluated the effect of a constant electrical field on bone growth around dental implants.

Materials and Methods: Four mongrel dogs were used in this study. Sixteen dental implants were placed immediately after extraction of the first premolar and molar teeth. A constant electrical field (CEF) generator was placed in the mucoperiostal pouch created from the subperiostral dissection under the inferior border of the dog's mandible and connected to the experiment side fixtures. CEF provided 3 V of electrical potential during osseointegration. Histologic sections were stained with hematoxylin–eosin and observed under light microscopy. The sections were analyzed histomorphometrically to calculate the amount of newly formed bone. Statistical analysis was performed with SPSS 11.0 computer software ($\alpha = 0.05$).

Results: At the end of the first stage of the osseointegration (90 days) CEF group sections showed enhanced growth of the trabeculae compared with the control group. Statistical analysis revealed significant differences between experimental and control groups. Bone contact ratio was statistically significant in the experimental group ($p = 0.001$). An increase in the local bone formation and bone contact ratio was observed with direct electrical stimulation of the implant and the bone area around the implant.

Conclusion: Minimal direct electrical current, which can produce an electrical field around the implant, can increase the amount of bone formation and decrease the time of osseointegration.

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INDEX WORDS: constant electrical field, magnetic field, osseointegration

OSSEOINTEGRATED IMPLANTS are widely used in dental implantology. The period between insertion of an implant and osseointegration of the implant into the surrounding bone is especially important for successful dental implantation.[1] The superstructure sits on the implant after osseointegration occurs.

Patients are often inconvenienced by the long

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period between the time of implantation and placement of prosthesis. The length of time before a titanium implant can become functional depends on the state of osseointegration.[2] The entire healing period of an implant in mandible or maxilla has been reported to be between 6 weeks and 6 months, although the healing period varies widely among individuals.[3] Therefore, development of procedures which enhance postoperative growth of bone in contact with dental implants and shorten the period of healing, which leads to an early restoration of the patient's occlusion, are required for successful oral implantology.[2,4]

Bassett et al reported that osteogenesis could be enhanced by the generation of electric potential.[5] Bone exhibits piezoelectric potential, streaming potential and steady potential.[6–8] Fukada and Yasuda[9] first demonstrated that dry bone is piezoelectric in the classic sense, i.e., mechanical stress results in electric polarization (the indirect effect); and an applied electric field causes strain (the converse effect). The piezoelectric properties of the bone are of interest in view of their hypothesized role in bone remodeling.[10] Becker[11,12] has also explored tissue electrical properties in connection with growth, repair, and regeneration. For example, partial limb regeneration in rats was stimulated by application of weak electrical signals.[13] Three major devices have been used for electrical stimulation of bone healing: the direct current stimulator,[14] inductive coupling,[15] and pulsed electrical electromagnetic field.[16] In current levels between 5 and 20 μA, progressively increasing amounts of bone are formed.[16] In a hydrated bone a minimum of 1.5 V are necessary to create 5 to 20 μA.[15] Matsumoto et al[2] proved that a pulsed electromagnetic field promotes bone formation around dental implants in animal models. Possible mechanisms underlying pulsed electromagnetic stimulation of osteogenesis includes promotion of vascularization, collagen production, and/or osteogenic cell proliferation and differentiation.[17,18] Ochi et al[19] demonstrated that capacitive coupled electrical field stimulates bone healing around endosseous implants in rabbit femurs. Generation of a constant electrical field via current electrical stimulation has proven bone healing properties.[14] Application of this kind of electrical field in conjunction with dental implant systems may promote osseointegration and accelerate oral functional rehabilitation of patients. The present study was conducted to evaluate the effect of applying a constant electrical field in the promotion of osseointegration after immediate implantation in a dog mandible.

Materials and Methods

Four adult mongrel dogs (weighing between 20 and 30 kg) with healthy teeth were used in this study. The experimental protocol was approved by the Institutional Animal Care and Use Committee of Tehran University of Medical Sciences. The dogs were premedicated with Xylazine-HCl (1 mg/kg) (Xylazine 2%, Alfasan, Woerden, Holland) intramuscularly, and atropine sulphate (0.05 mg/kg) (Atropin 0.5, Daroupakhsh Pharmaceutical Mfg Co., Tehran, Iran) subcutaneously. This was followed by general anaesthesia with sodium thiopental (10 mg/kg) (Nesdonal, Specia, France) intravenously. After induction of general anaesthesia, the oral cavity was cleaned with Povidine Iodine (Daroupakhsh Pharmaceutical Mfg Co.) mouthwash solution. Infiltration anaesthesia was applied to the mandibular body area. A crestal incision was made from the distal side of the mandibular first premolar to the mesial side of the mandibular second molar with the releasing incision in the mesial side. A mucoperiosteal flap was raised to expose the bone surface. Dissection through the inferior border of the mandible created a mucoperiosteal pouch in the experimental site of the animals. First and second premolars were extracted gently in the both the left and right sides of the mandible.

Sixteen dental implants (Paragon Implant Co., Encino, CA) were used in this study. The diameter of the implants was 4.1 mm and the length was 12 mm. Teeth extraction sockets were prepared using a twist drill (# 2.3, 2.8, 3.4 mm diameter, Paragon Implant Co.) and cooled with the external irrigation of normal saline. The depth of implant insertion was prepared 4 mm beyond the socket of the teeth to provide enough primary stability. The implants were placed in the osteotomy side by self-tapping.

Eighteen-gauge gold wires were made and were connected to the positive and negative poles of the 3-V microlithium cell. (Mitsubishi, Tokyo, Japan). A thin layer of Biosilicone (pSivida, BGC Centre, Perth, Australia) provided biocompatibility of the batteries. Silicone covered the energy cell and the wire separately. This constant electrical field generator was placed in the mucoperiosteal pouch, which was created in the buccal aspect of the experimental side (Fig 1). Closing the cover screw over the gold wires stabilized the connection (Fig 2).

Implants were placed in the control side with minimal dissection of the mucoperiosteal flap. The flap was sutured with Vicryl 3–0 (Ethicon, Sommerville, NJ)

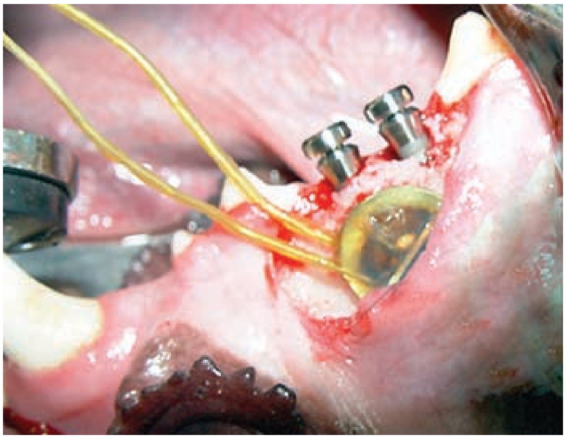

Figure 1. Insertion of the constant electrical field generator beneath the mucoperiosteal pouch.

sutures, and the animals were placed on a soft diet regimen for 1 week. Direct electrical current from 3-V batteries began to stimulate the experimental implant group after the closure of the flap and persisted for 30 days. The dogs received cefazolin (22 mg/kg BID) intramuscularly for 5 days post-surgery as an antibiotic prophylaxis. The electrical current of the generator to the implants was evaluated every 4 days and an average of 2.9 V was measured each time.

Each dog was sacrificed 90 days after insertion of the implant. The animals were sacrificed with an overdose of sodium thiopental and subsequently perfused through the carotid arteries with a fixative consisting of a mixture of glutaraldehyde (5%) and formaldehyde (4%) buffered to pH 7.2.

The mandibles were removed and placed in 10% formalin for an additional 10 days. After dehydration by using ascending series of ethanol (60% to 100%), the specimens were embedded in the glycomethacrylate

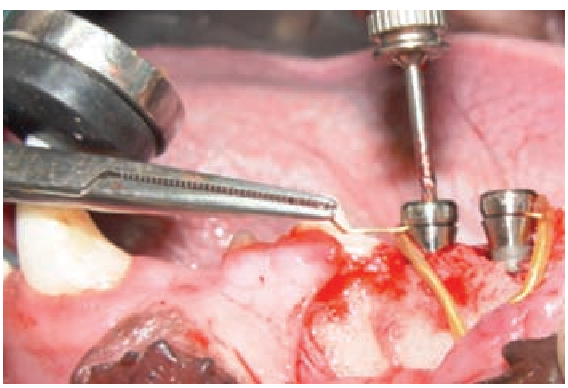

Figure 2. Stabilizing the connection between the implants and the CEF generator with gold wire.

A

B

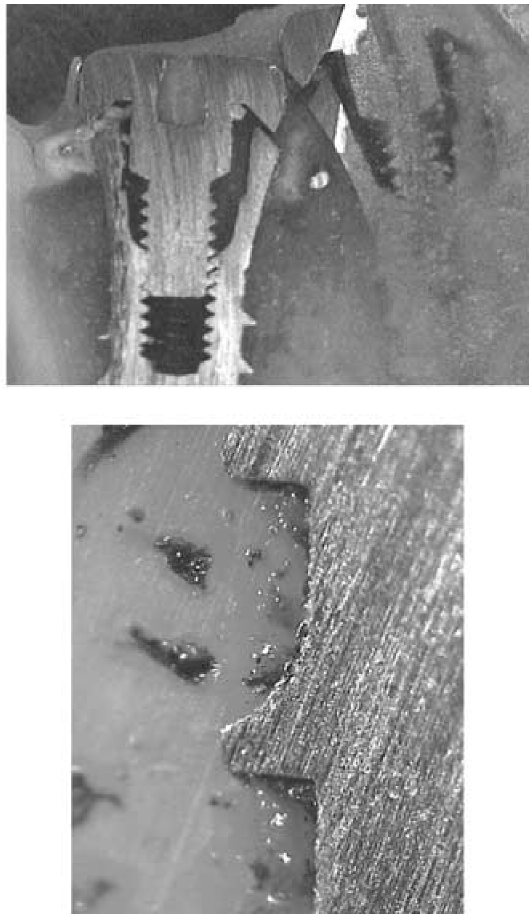

Figure 3. Photomicrographs show the bone in contact with the implant surface along the majority of the implant surface. (A, ×2.5; B, ×10)

(Technovit 7200; Heraeus Kulzer GmbH, Wehrheim, Germany). Undecalcified ground sections were prepared with the Accuton 50 (Struers A/S, DK-2616, Copenhagen, Denmark) saw machine through the center of the implants, and three cuts were arranged mesiodistally. The sections were polished to a thickness of 30 μm using a grinding system (EXAKT Apparatebau, Norderstedt, Germany) for histological examination under light microscopy.

Quantitative and qualitative computer-based analysis was performed on a microphotographed plate of the bone ingrowth in contact with implants. Central sections were used for analysis of bone percentage in contact with implants. The photomicrographs of the implant visualizing both sides were observed via stereo microscope (Olympus, SZX 9 Tokyo, Japan). With a high resolution CCD Video camera (3077 CCD, JVC, Tokyo, Japan) adapted to the microscope, the resulting high and low-magnification images were scanned into a computer and subjected to image analysis using NIH

Table 1. Comparison of Bone Contact Ratio (BCR) between the Two Groups

Experimental Group	*Control Group*
0.5	0.49
0.52	0.50
0.52	0.50
0.52	0.52
0.53	0.48
0.55	0.46
0.53	0.47
0.56	0.45

Image 1.57 software (National Institutes of Health, Bethesda, MD)[2] (Fig 3A, B). The images were digitized into 800 × 600 pixels with gray value between 0 and 250.[4] The amount of bone and non-bone in the selected peripheral region of the implant was calculated. The percentage of the bone was calculated directly through the computer. The bone contact ratio was defined as the percentage of the length of the new bone that was in contact with the implant, out of the total length along the surface of the implant (length of new bone in contact with implant/length of implant/100) (Table 1). The sections were stained with hematoxylin–eosin (H&E) for qualitative investigation. The measurements were performed directly in the eyepiece of a light microscope (Nikon E 400, Edipsa, Tokyo, Japan) using × 10 magnification and 2.5× zoom (Fig 4A and B).

Results

Using a gold wire connection, constant electrical field (CEF) was applied to 8 out of 16 implants inserted into the mandibles of four dogs. The rest of the implants acted as a control group. The mean values of bone contact area were calculated for each group (Table 2). The groups were compared using non-parametric Mann-Whitney U test. The results and statistical analysis were analyzed with SPSS 11.0 computer software (SPSS, Chicago, IL). Statistical analysis revealed significant differences between experimental and control groups (p value = 0.001).

During the experiment none of the implants exhibited mobility or any inflammation in the

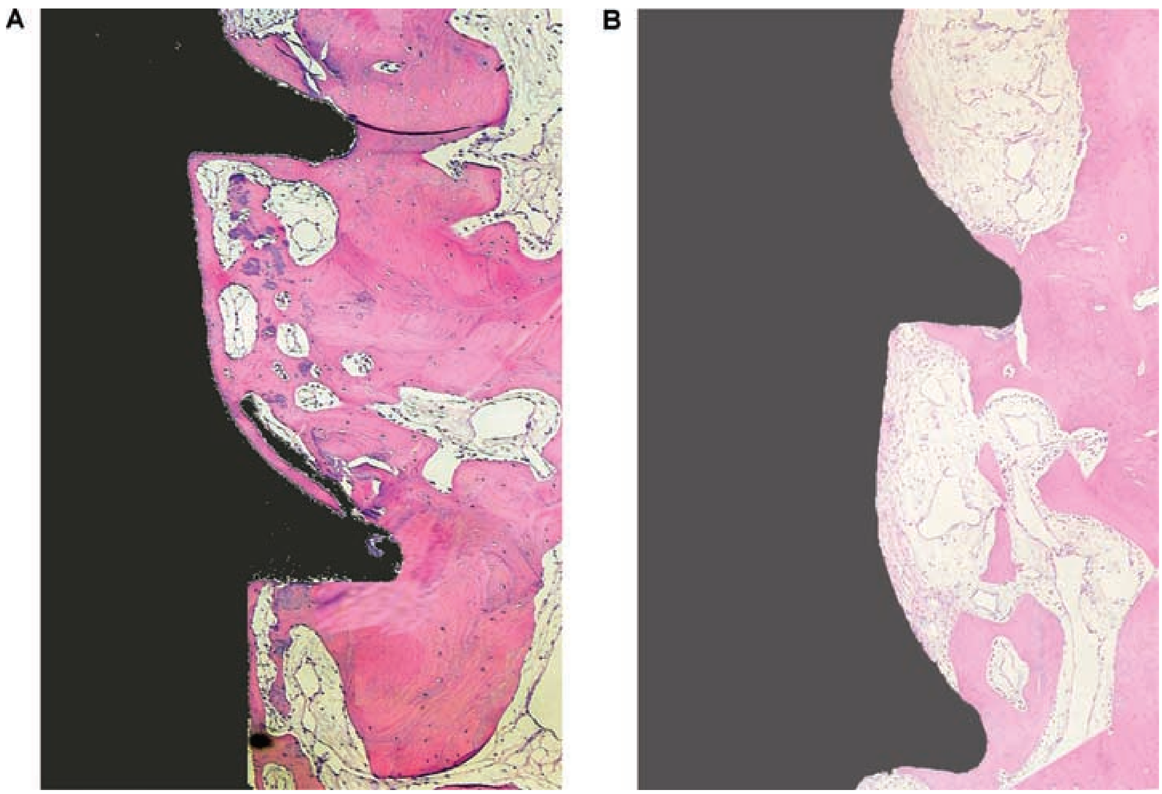

Figure 4. Sections obtained 90 days after surgery. The specimen without CEF (A) showed more cavities in the bone and more immature trabeculae. The specimen with CEF (B) showed greater maturation of bone and more irregular mature osteon formation of the bone.

Table 2. Mean Values of Bone Contact Area

	Mean	*Standard Error*
Experimental group treated with CEF*	0.5288	0.0066
Control Group	0.4838	0.00822

*Constant electrical field.

surrounding gingival tissue. The prepared pictures in the light microscope demonstrated bone growth around implants in both the experimental and the control groups. The bone contact ratio of each experimental group is summarized in Table 1. The bone contact ratio of the mandibular bone in contact with the implants in the experimental side was slightly larger than control side. The mean bone contact ratio in the experimental group was more than the control group (Fig 5). Most of the new bone contained large number of osteocytes and had been laid down parallel to the surface of the implants on the side of the edges of the drilled hole. A thin layer of lamellar trabecular bone was formed on the surface of the implants.

Discussion

Electrical properties of bone are relevant not only as a hypothesized feedback mechanism for bone remodeling, but also in the context of external electrical stimulation of bone to aid its healing and repair.[16,19] Every living cell has a membrane potential. Low energy membrane tickling produces membrane excitement, and membrane excitement in turn produces cellular excitement. Excited cells do the same job as bored cells, but at a harder and faster rate.[20] The type of electrical stimulation used in this study (20μA, 3 V) had previously been shown to elicit osteogenesis.[16,21] The range of electrical current that produces osteogenesis is relatively narrow and model dependent.[15,16] Osteonecrosis rather than osteogenesis occurs if the current is too high.[21] Pulsed electromagnetic fields (PEMFs) are widely used to promote bone healing in orthopaedic treatment. The effects of PEMF in oral implantology following implant placement have recently been reported.[22] Aaron et al[23] reported electrical and magnetic fields, upregulated mRNA expression for, and protein synthesis of, transforming growth factor-β_1 coincident with increases in ECM protein and gene expression. It is assumed that the constant electrical field initiated an increase in localized calcium deposits, which neutralized the net negative charge of tissues and allowed the subsequent vascularization of osteogenesis.[24] The initial hypothesis in this study was to employ an applicable kind of electrical current to promote osseointegration. None of the preceding devices used for electrical stimulation had employed implants to generate an electrical field in the surrounding bone. The bone around the implants in the experimental side of the animals was affected not only by the direct electrical current, but also the electrical field generated between the two implants. Constructing the simple electrical device and intraoral handling in this study could anticipate the development of electrical current generator implants in the future. The clinician should be aware of new methods but must try to keep them in perspective, since good results are the objective. A slight increase in the bone contact ratio in the experimental group may suggest further research with more subjects. The limited number of animals limited the result of this study. Although statistical analysis becomes slightly weak when the total number of observations in the study are small (N < 30), statistical significance is not synonymous with clinical significance. The author wishes to emphasize the lower morbidity of this technique in comparison with other electrical field generators. Modifying the shape or magnet cover screw, gingival formers, and abutments can influence the osseointegration, decrease the healing time, and promote the functional rehabilitation of patients.

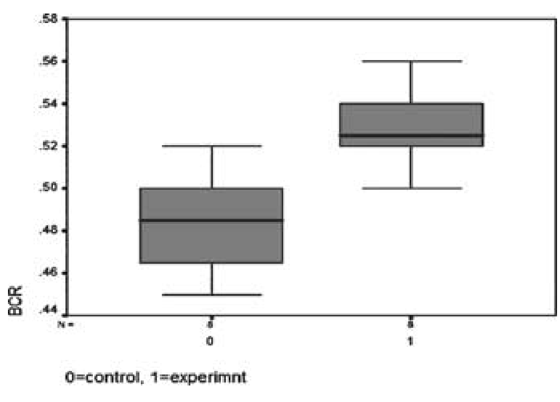

Figure 5. Mean value of the BCR between the groups. The experimental group showed significant statistical difference.

Conclusion

The results of this study suggest that local application of an electrical current during osseointegration may stimulate bone formation around dental implants and decrease the time for the first stage of the implant surgery.

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