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Research Article

Role of Direct Current Electrical Stimulation in Dental Implant Osseointegration - A Pilot Study

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Abstract

Electrical stimulation has been therapeutically used in enhancing bone healing especially in situations of fracture. Three methods are commonly used for electrical stimulation: direct current stimulator, inductive coupling and pulsed electro magnetic field. In order to find out whether direct current stimulation can be used to improve osseointegration in dental implant treatment, the present study was designed. A custom made implant which allowed bone ingrowth was used. An Electrical stimulator that provided 20μA current was designed and fabricated. Dogs were used to conduct the in vivo experiment. Electrical stimulation for a period of 21 days gave positive results with densitometric measurements.

Keywords: Electrical Stimulation; Osseointegration; Titanium Implants; Densitometer

Introduction

Success of a dental implant is synonymous with osseointegration. The earliest time frame with which osseointegration is obtained is a fact favored both by the clinician and the patient. Once established, osseointegration must be maintained and it is very critical to keep it free from infections. Inadequate or failed bone implant contact may result in the loosening or eventually the loss of the implant [1-3]. Titanium dental implants integrate with the surrounding jaw bone within a period of few months. Scientific evidence suggests that the healing process of dental implants fall within 6 weeks to 6 months. This is subject to individual variation and the loading protocol adopted by the clinician. Three different protocols are generally followed at present.

- Immediate loading: Loading the implant within one week after placement
- Early loading: Loading the implant between one week and two months
- Conventional loading: Loading the implant after two months of placement [4]

For early loaded implants, an enhanced or rapid osseointegration is a desirable requirement. It is also indicated in situations where the bone quality is considerably compromised. To initiate rapid osseointegration, effective use of an additional stimulus is required [5-7]. Electrical stimulation has a potential therapeutic effect and enhances the process of osseointegration in dental implant treatment by promoting the osteoblastic activity and thereby bone formation. The history of electrical stimulation can be traced back to early 19th century, but in the initial phases the rationale of its therapeutic effect was not fully understood. Sympathetic nerves are widely distributed in the bone tissue and which regulate the bone formation through the adrenergic receptors present in the osteoblasts [8-10,14].

In the recent past electrical stimulation has attracted the attention of research workers and experiments were conducted with in vitro and in vivo models. Initially electrical stimulation was made use of in fracture healing but later it found applications in the field of dental implants. Electrical stimulation was carried out through cathodic electrodes placed near the fracture line. Most of the studies have experimented with either direct current (DC) or pulses. DC stimulation of 5, 15, and 25 μA has been tried in cellular studies using human foetal osteoblasts. 25 μA gave favourable results in stimulating the cells [11]. Bins Ely., *et al.* have conducted experiments

in beagle dog model using 10/20 µA for 7/15 days respectively and observed high bone implant contact with 20 µA for 15 days [12].

Electrical stimulation has received conceptual recognition in obtaining faster osseointegration for the dental implants. Very few studies have been conducted using *in vivo* animal models. When animal experiments are optimised, it may clear the path to human trials, at least in the compromised situations. In this context the present animal experiment was planned with the following objectives.

Objectives

- To evaluate the effect of electrical stimulation on bone growth at implant site using a current of 20 µA.
- To compare the bone growth at the stimulated and unstimulated sites.

Methodology

The present study was conducted to evaluate the effect of electrical stimulation on osseous growth. The experiment was conducted according to the ethical principles followed in the animal house of the Medical college, Trivandrum. Three dogs with seven years of age were selected as the experimental animal models. The dogs were kept under observation in the animal house for ten days to rule out the presence of infections like rabies. During the observation period, balanced diet was provided and the body weight was monitored periodically which served as an index of health of the animals. In the experimental animals specifically designed bone growth chambers were implanted. Provisions to stimulate the bone electrically were also incorporated.

Electrical stimulator

Electrical stimulator was designed to generate a constant current of 20µA. The stimulator required a power source of 4.5V (3 alkaline button cells) to ensure uninterrupted power supply. The circuit diagram is given in figure 1. The power from the stimulator was passed to the bone through two screw shaped electrodes positioned on both sides of the bone growth chamber (Figure 2).

Titanium bone growth chamber

The chamber was originally designed by Albrektsson., *et al*. [13] which was cylindrical in shape with an outer diameter of 7mm and 7mm height. The implant consisted of three sections - A, B, C and held together by two titanium screws passing through the three sections. On assembly, the cylinder had two canals of 1mm diameter passing through the junctions of the three sections – between

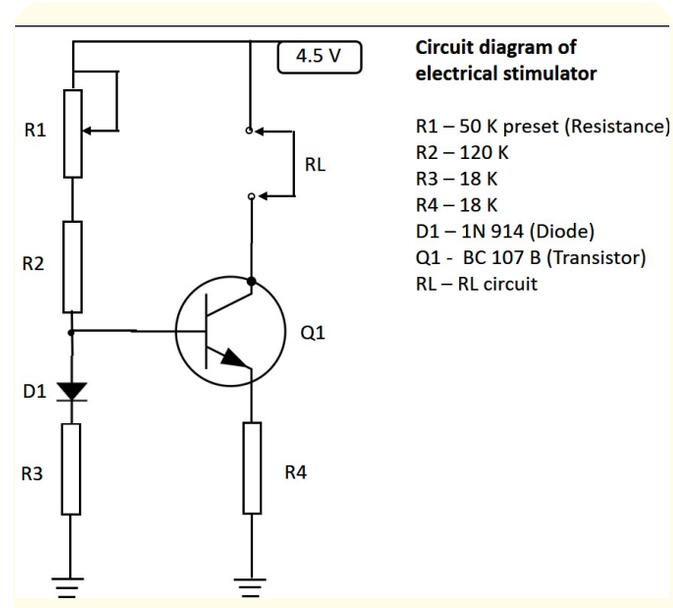

Figure 1: Circuit diagram of electrical stimulator.

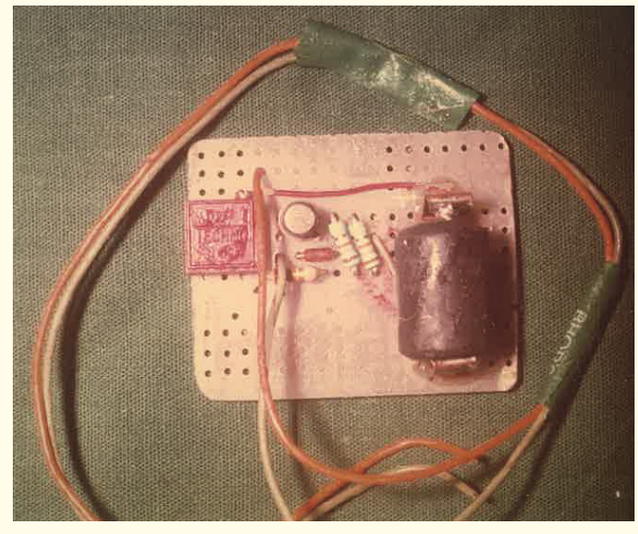

Figure 2: Components of the electrical stimulator.

A and B one canal, between B and C another canal (Figure 3, 4). Section A had a channel prepared to hold a screw driver and the top edge was threaded to be held in the bone. In each experimental animal, two bone growth chambers were implanted; one in the angle of the mandible which was electrically stimulated and another one in the femur which was not stimulated and served as a control (Figure 5). Electrical stimulation was carried out continuously for 6 hours every day for a period of 21 days. Bone in growth that occurred in the canals was evaluated by a radiograph after a period of three weeks. The quality of the ingrown bone was assessed by X-ray densitometer (Figure 6).

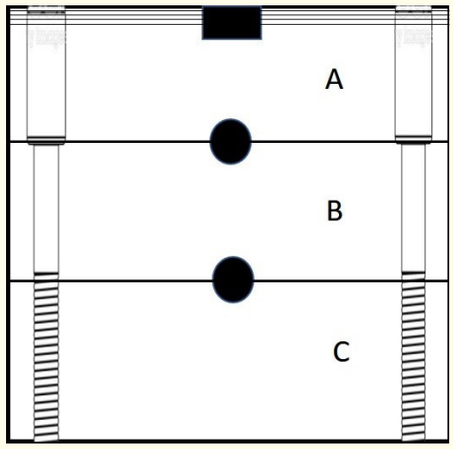

Figure 3: Bone growth chamber.

Figure 4: Components of the bone growth chamber.

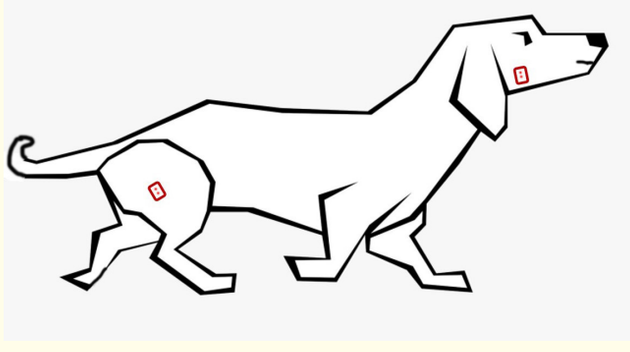

Figure 5: Schematic diagram of experimental animal with implants.

Figure 6: Densitometer (web page).

Surgical procedure

The experimental animals were anaesthetised with Pentobarbitone sodium at a dosage of 1 mg per kilogram body weight. After surgically exposing the bone through blunt dissection, the bone growth chamber was implanted both at the experimental site in the mandible and at the control site in the femur. The osteotomy site was prepared by surgical drills and the implants were tightly positioned by a screw driver (Figure 7,7a). Before placement of the implant, the canals were filled with autologous blood and marrow with a syringe. The position of the implant was such that the upper canal that passed between section A and B was well within the cortical bone. The electrode screws were placed on both sides and 5mm away from the implant, at the experimental site. The electrodes were placed intra cortically and which were protruding into the marrow space (Figure 8). One electrode was cathode and the other was anode. The electrode heads could connect the lead wires from the stimulator. The wound was closed carefully in layers and sutured. The electrode heads were visible after suturing. The animals were maintained on balanced diet thereafter. The experimental animals were given antibiotics - Procaine penicillin (4 lakhs units per day) for five days. After 21 days, the implants were removed surgically without disturbing the bone grown into the canals of the implants. The animals were maintained in the animal house for two more weeks. The bone growth chambers were carefully opened and the tissue from the canals were separated and fixed with formalin. The specimens were then radiographed.

Radiographic Technique

The tissue grown into the canals was carefully separated and fixed with formalin. It was then placed on a Dental x-ray film.

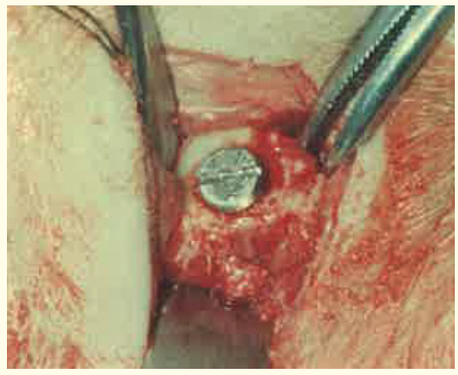

Figure 7: Bone growth chamber implanted in the bone.

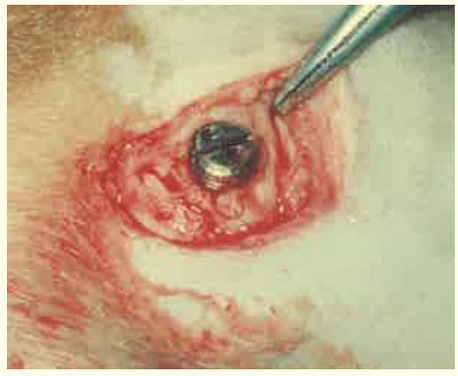

Figure 7a: Bone growth chamber implanted in the bone.

Figure 8: Electrode screw.

An Oralix X-Ray machine (KVA 60, exposure time of 0.5 second) was used to radiograph the ingrown tissue. The X-ray source - film distancewas kept at 60 mm. All the Radiographs were developed and fixed simultaneously. They were dried and subjected to Densitometric measurements.

Densitometric technique

Densitometer is a device that measures the density or the degree of darkening of a photographic or X ray film by recording photometrically its transparency. Densitometers consist of a light source aimed at a photoelectric cell and an analogue meter or integrated circuitry to show the data. An X-Ray densitometer (Figure 6) (X-Rite black and white transmission densitometer model 333C.) was used for comparing the density of the radiograph of the bone obtained from the control site with that of the test site. Densitometric values increase with an increase in the blackening of the film. When the bone is formed, the values decrease correspondingly.

The methodology is summarised in the flow chart (Figure 9,10).

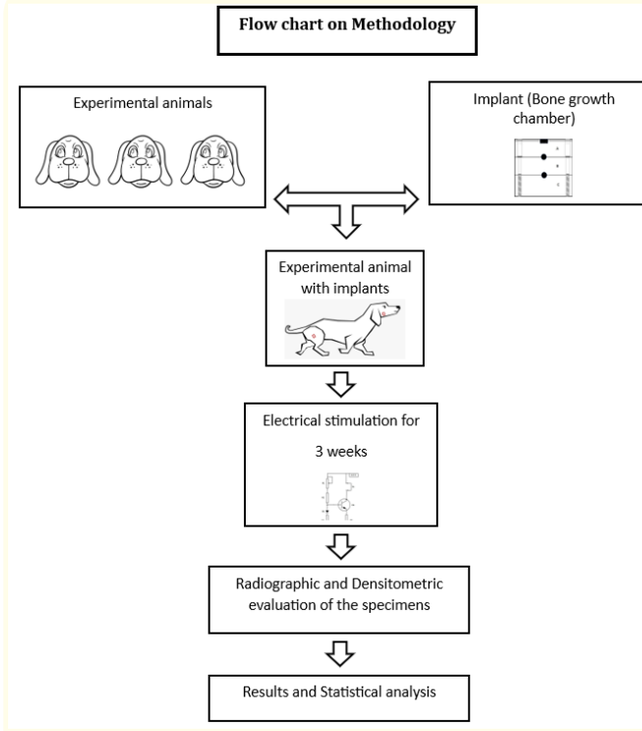

Figure 9: Flow chart on methodology.

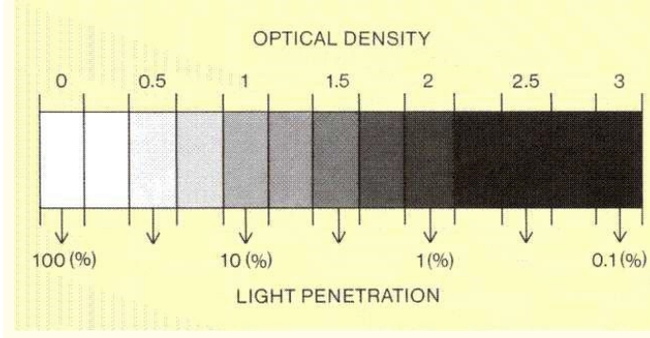

Figure 10: Scale of optical density.

Results

Specimens were collected from experimental sites and control sites. Electrical stimulation was done at the experimental site for a period of 3 weeks. The specimens were then radiographed and the radiographs were subjected to densitometric evaluation. Densitometer transmits light which passes through the film. The amount of absorption of light is shown numerically by the densitometer. The values are in fact a logarithmic expression of the reciprocal of the transmittance or absorbance. The commonly used scale is given in Fig 10. The densitometric values obtained in the present study are given in table 1.

Test procedure

Null hypothesis

There is no significant difference between the densitometric values obtained for the samples harvested from the experimental sites (jaw bone) and the densitometric values of samples obtained from control sites (femur). Statistical testing was performed with an alpha level equal to 0.05 ($\alpha = 0.05$).

Decision criterion

If $P < 0.05$, the null hypothesis was rejected and accepted the alternate hypothesis. If $P > 0.05$, the null hypothesis was accepted.

Statistical technique used: Student's t-test.

Table 1 shows the values obtained from the radiographs of samples when subjected to densitometry. Test site mean value was 0.55 ± 0.0261 whereas, the mean value obtained for control site specimens was 0.615 ± 0.2880. This indicates that there is evident bone formation and the values are superior at the experimental site where electrical stimulation was employed. Numerically lower densitometric values indicate higher bone formation. In the present study the difference is statistically significant ($p < 0.05$).

Discussion

In the late 1950s, Fukada and Yasuda described the characteristic piezoelectric property of bone and its role in bone formation. When bone is subjected to mechanical stress, endogenous electrical fields are generated which are capable of stimulating bone healing [10]. Three methods of electrical stimulation are usually made use of viz. direct current electrical stimulation, capacitive coupling and inductive coupling. These were made use of initially in areas of delayed bone healing. The use of electrical stimulation in implant treatment has become popular only in the recent past. Direct current electrical stimulation is an invasive method and that is selected for the present study. Professional bodies have started approving the electrical bone growth stimulators especially in fracture non unions and in osteoporosis [15]. However electrical stimulation remained popular only with 32% of orthopaedic surgeons. Majority of them pointed out that electrical stimulation was very expensive and the results were not consistent [16]. In the last decade scientific studies were generated with electrical stimulation, using in vitro and in vivo models to promote osseointegration. However human experiments were seldom reported [17]. Bone implant interface gets improved through direct current (DC) stimulation, possibly by enhancing the osteoblastic function but the exact mechanism of action needs further exploration [1].

Current controlled stimulation seems to give positive results in in vivo studies using animal models like rabbits, sheep and dogs. 5 to 50μA current was used in most of the studies. Titanium implants (Ti6Al4V) were used and which were located in mandible, tibia and femur. In the present study 20μA current was employed, titanium implant was used and the site chosen was mandible and femur. Majority of the studies have stimulated the implant itself and which served as cathode. Independent electrodes were used for cathode and anode in a few studies and the bone formation was mainly related to the cathode [6,19]. In the present experiment, separate electrodes were used. In most of the studies reported, stimulation was done for 3 to 6 weeks of which 3 weeks was selected for the present experiment because it was a pilot study [17,18]. The duration of electrical stimulation in in vivo and in vitro studies did not follow a uniform time frame and in the present study Dergin's protocol was accepted because of the feasibility [6,19]. Considering the various protocols reviewed in different publications, the authors have accepted the following experimental protocol in the present pilot study: dogs as the animal model, mandible as the experimental site, femur as the control site, custom made titanium implant and electrodes, 20μA direct current, 6 hours of stimulation per day and 21 days of stimulation. After completing the entire period of experiments, the implanted bone growth chambers were surgically removed with the ingrown bone intact, avoiding the sacrifice of the animals.

Custom made bone growth chambers were implanted and electrically stimulated. The stimulators worked on a power source of 4.5V and it ensured uninterrupted supply of 20μA for the entire duration of the study. The bone growth chambers could be disassembled and the ingrown tissue specimens could be separated.

In animal models, bone growth that occurred was radiographically evaluated and the darkness of the film was measured with densitometer. In each experimental animal, two bone growth chambers were implanted. One implant placed in the mandible was experimental because it was electrically stimulated. One implant was placed in the femur which served as control. It was not electrically stimulated. From each implant, two specimens were obtained. In total six specimens were obtained from the test sites and six were obtained from the control sites. Mean control site value was 0.615

± 0.2880 and test site value was 0.55 ± 0.0261. The densitometer measures the darkness and gives the logarithmic values. When the darkness reduces, it indicates the formation of radio opaque material. Along with that the densitometric value also decreases. The values obtained indicate the formation of bone at a statistically significant level (Table 1). Results of the pilot study is very positive. However, it requires further validation with more samples and incorporating different electrical stimulants.

Implant number	Specimen number	Test site Reading	Control site Reading
I	1	0.57	0.60
I	2	0.55	0.65
II	3	0.53	0.61
II	4	0.51	0.62
III	5	0.56	0.57
III	6	0.58	0.64
Mean		0.55	0.615
Standard deviation		0.0261	0.2880

Table 1: Densitometric values obtained from the specimens of both control and experimental sites.

T value: -4.0973

p value: 0.002

$p < 0.05$.

Non invasive stimulation may be appropriate for dental implants and it may improve the compliance rate. Non-invasive stimulation uses electromagnetic fields delivered to target tissue, utilising inductive coupling or capacitive coupling mechanisms [20]. More studies are required to optimise the duration of electrical stimulation so that fast osseointegration can be achieved. Studies can also be done to collect more histo morphologic evidence of enhanced osseointegration and bone healing.

Conclusions

Within the limitations of the pilot study, it was observed that direct current stimulation can improve bone growth and there by osseointegration.

Invasive methods, though effective in animal models, have limitations to be used in patients requiring dental implants.

Non-invasive methods like inductive or capacitive coupling have to be explored as future alternatives to direct electrical stimulants.

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Figure credit

Figure 10: http://www.sprawls.org"www.sprawls.org