Bioelectric Perturbations in Orthodontic tooth movement

Dr. Kenneth F. H. Tan\textsuperscript{1*} MDS ; Dr. V. Surendra Shetty\textsuperscript{2#} MDS; Dr. Subraya Mogra \textsuperscript{1#} MDS

1 Professor, 2 Professor & Head

*Department of Orthodontics, Sri Siddhartha Dental College & Hospital, Tumkur
# Department of Orthodontics, Manipal College of Dental Sciences, Mangalore

Journal of Dental Sciences & Research 1:1: Pages 41-49

Abstract:

Introduction: The purpose of this study was to evaluate whether the external application of pulsed electromagnetic fields (PEMF’s) could enhance the amount of orthodontic tooth movement in young adult guinea pigs.

Method: twelve young adult guinea pigs were divided equally into the experimental and control groups. Both groups were fitted with a customized coil spring to the upper central incisors. the experimental group animals were placed within an apparatus which generated PEMF’s for eight hours per day for ten days, whereas the controls were not. Daily measurements of amounts and rate were done. At the end of the ten day study period, the animals were sacrificed and histological section of the teeth and supporting bone were made and analyzed.

Results: the experimented group of animals showed significantly increased rates and amounts of tooth movement from the 4\textsuperscript{th} experimental day 9 onward. (p <0.05) They also showed increased amounts of orderly bone deposition. Histologic sections also showed increased number of osteoclasts. (p< 0.001)

Conclusion: The result of this experimental animal study supports the premise that PEMF’s increased the rate and amount of orthodontic tooth movement.
INTRODUCTION

The essence of orthodontic treatment is the movement of teeth through alveolar bone to obtain a more perfect dental occlusion, and is the classic paradigm for mechanical stresses causing clinical changes.

When force is applied to a tooth, it tends to move. But how far it moves, and how fast or whether it moves at all depends upon the reaction of the environmental tissue to that force. Accurate and precise control of tooth movement can be optimized with the proper use of mechanics and knowledge of the subsequent tissue response. Thus orthodontic treatment is inescapably mechanical - it is subject to physical laws governing force mechanisms, and biologic principles controlling tissue reactions to force stimuli.

The mechanics of orthodontic movement are well understood, for most of the physical laws governing the application of mechanical force have been known for centuries. The biology of orthodontic movement, however, is less well understood. Since 1953\(^1\), when Yasuda first demonstrated that a mechanically stressed bone exhibited electrical potentials, electrobiology has advanced tremendously with investigators being fascinated with the study of the electrical properties of bone. Low level electrical currents and potentials have been found to have the capability of bringing about major biologic effects of a very basic nature.\(^2\)

Basic scientific interest has progressed to the stage where it is now possible to apply electromagnetic fields with considerable success.

Perhaps the most challenging aspect of pulsed electromagnetic fields (PEMF’S) is their relative newness as a therapeutic agent and the fact that they cannot be “felt, seen, smelled, or tasted". The use of PEMF’s is a reinvention and reapplication of an old idea benefitting from the application of modern technology. If endogenous stress-generated potentials affected bone remodeling, then perhaps electrical signals applied externally with simultaneous application of mechanical stress could result in enhanced cellular response. The ability to enhance the rate of tooth movement at the cellular level by means of PEMF’s would have major clinical significance. In addition to providing information on the underlying mechanisms controlling tooth movement, the technique might help in enhancing orthodontic tooth movement in adult patients which by nature slow down with age.

Therefore, the aim of the present study was to enhance the rate and amount of orthodontic tooth movement in young adult guinea pigs by the external application of pulsed electromagnetic fields.

MATERIALS AND METHODS

This study was performed on 12 guinea pigs (Cavia porcellus) weighing about 350-400 grams and 9-10 weeks old at the start of the study, divided into two groups, the experimental group and the control group, of six animals each. All the animals had coil springs fitted to the upper incisors. The compressed coil spring used to deliver the orthodontic force was fabricated from 0.010 inch Supreme grade Australian wire (A.J. Wilcock,T.P. Laboratories). The spring had a helix with 3 turns and an internal diameter of 3mm. The arms of the spring were about 15mm long with small single coils incorporated about 9mm away from the distal end of the helix. The legs were approximately 35\(^0\) to each other such that when compressed till the small coils were 1mm apart, a reproducible force of 12 grams was produced. This force was verified using
a Dontrix stress-tension gauge (E.T.M. Corporation U.S.A). The small single coils acted as stops against the upper incisors and were ligated together with stainless steel ligature wire to facilitate insertion.

Animal Holders:

Two special animal holders were fabricated from clear polymethyl methacrylate sheets to contain the guinea pigs and limit movement during the time of the experiment. The pulsed electromagnetic field device was constructed as planned below:

This device comprised of 3 units.

Unit A – Two coils arranged in parallel i.e. in a Helmholtz configuration

Unit B – Driver unit. This is the electronic circuit to drive the coils.

Unit C – Pulse generator circuit which controls the driver unit.

Unit A - The coils:

Each coil consisted of 40 turns of 17 - gauge enameled copper wire insulated with varnished cotton tape. The coils had an internal diameter of 14cm and were fitted onto clear acrylic sheets of dimension 25 X 25cm and 4mm thickness. These sheets along with the coils were positioned parallel to one another on a plywood pedestal and separated by an intercoil distance equal to the radius of the coils i.e. 7cm, so as to get a uniform magnetic flux density between the coils. The coils were connected in parallel electrically and placed parallel to the earth’s magnetic field to avoid any interference to the induced magnetic field.

Unit B and C - Driver and Pulse Generator Circuits.

These components were soldered onto a printed circuit board. The pulse generator circuit was set to produce a pulsed electromagnetic field with a frequency of 100 Hertz. The electronic units were connected to a 12 volt, 2ampere regulated power supply unit plugged into the mains outlet. On the first experimental day, the animals were anesthetized with pentobarbital sodium (Nembutal).

A small hole was drilled from the labial to the lingual aspect of each upper central incisor with a 1/4 round tungsten carbide bur under copious water spray coolant. The holes were placed about 2mm from the incisal edge to avoid pulpal tissue and to ensure sufficient tooth structure for normal incisal wear. The distance between the two holes was measured using a Boley gauge accurate to the nearest tenth of a millimeter. The portion of the arms of the spring distal to the stops were annealed. The spring was placed intra-orally along the palate of each animal.

The annealed arms were passed through the holes in the incisors till the stop coil appressed against the palatal surface of the tooth and the arms were cinched to keep the spring locked in place. The spring was then activated by cutting and removing the ligature ties.

The experimental group:

The six animals were labeled $E_1$ to $E_6$ and each was placed in the animal holder. Thermocol blocks were used to support the animal holder between the coils such that the head of the animal was centered both antero-posteriorly and vertically in the pulsed electromagnetic field. Each experimental animal was exposed to the pulsed electromagnetic field for 8 hours per day for a period of 10 days.
The Control Group:

The six animals were labeled $C_1$ to $C_6$ and were placed in similar holders and conditions as the experimental group except for the absence of the pulsed electromagnetic field. Daily measurements using the Boley gauge were made of the amount of separation of the two upper incisors using the drilled holes as reference points. At the end of the tenth experimental day, the animals were sacrificed by the physical method as advocated by UFAW (Universities Federation of Animal Welfare) and a block section of the maxilla including the incisor teeth and surrounding bone was surgically removed. The specimens were placed in individual labeled bottles ($E_1$ to $E_6$ for the experimental group and $C_1$ to $C_6$ for the control group) containing 10% formalin fixative solution for 24 hours prior to decalcification. Decalcification was done using formic acid solution.

After decalcification, the specimens were embedded in paraffin wax sections perpendicular to the tooth’s long axis were cut at 6 micron thickness and were stained with eosin and hematoxyllin. Histologic evaluation to gain quantitative information regarding the number of osteoclasts and qualitative information regarding deposition of bone lateral to the premaxillary suture area was done using a LEITZ LABOR-LUX microscope under low power (lax) and medium power (40x). Means and standard deviation were calculated for the cumulative and daily incremental tooth movement, and the osteoclast count. Student’s ‘t’ test for independent groups was performed and a significance level of $P = 0.05$ was selected.

DISCUSSION

The data from this study tend to support the results of the pioneer study by Stark and Sinclair that pulsed electromagnetic fields are capable of increasing the rate amount of orthodontic tooth movement in a sample of guinea pigs. The increase in rate amount of orthodontic tooth movement demonstrated in the present study using PEMF’S of 100 Hertz frequency over a 10 day experimental period was similar in nature to that of Davidovitch’s study using direct current stimulation in cats.

The amount of tooth movement between experimental and control groups was insignificant for the first three days but from the fourth day onwards, the PEMF stimulated animals showed significant increase in the amount of tooth movement. By the tenth day the PEMF stimulated animals showed far greater amounts of tooth movement than the controls. These differences in findings may be accounted for by the PEMF’s stimulating intracellular biochemical changes which then have to manifest as a cellular response, reaching a significant level from the fourth day onwards. The exact mechanism of how exactly bioelectric perturbation due to PEMF’S bring about the tissue response is not known. However, many hypotheses have been proposed and research to unravel the mystery is being done.

Davidovitch has suggested that mechanical stress induced electrical potentials in bone may be the signal activating the cells that participate in the remodeling process. He also suggested that electrical stimulation in conjunction with mechanical force can increases the rate of tooth movement. Therefore it is possible that PEMF’s and orthodontic forces may function in a synergistic manner.

Clusters of cholesterol of charged molecules of proteins, lipids, lipoproteins and cholesterol form receptor sites in the
cell membrane. These molecules "flow" at different rates. There are complex charge patterns as the molecules interact with each other, the cytoplasm and the plasma surrounding them. These charges may be altered by the induced current flow on the membrane surface through the electrolyte environment in which it dwells. Thus, ions may move across the cell membrane.

Critical chemical concentration gradients may change, activating various biological mechanisms. Receptor sites may be activated by the change in charge so that low concentration of like molecules may cause an enzymatic cellular response. It is likely that cation flux changes, and changes produced by ATPase are produced. In fact, changes in cAMP concentration and calcium ions flux have been noted. This apparently changes the physical characteristics of the cell inducing a higher degree of receptivity and reactivity. There are changes of shifts the DNA synthesis in the cell cycle with increased number of cells entering the DNA synthesis phase and cell proliferation may be enhanced.

The PEMF may also be providing the signal for the recruitment of undifferentiated stem cells into osteoblastic and osteoclastic processes.

The mechanically stress-induced piezoelectric currents generated in alveolar bone have been postulated to provide the signal for the directionality of the remodeling process i.e. the resorption or deposition, with the generalized enhancement of osseous activity being a function of the application of PEMF’s and so a change in a highly charged molecule may eventually affect all the changed by PEMF’s and so changes in proteoglycan’s structure can lead to local change in pH, oxygen consumption and ultimately calcification.

The increased number of osteoclasts, strong reversal lines and Howship’s lacunae observed in the PRW stimulated animals confirms the earlier report of Stark and Sinclair. Some studies have indicated that increased local synthesis of prostaglandins initiates the differentiation of monocytes into activated osteoclasts and that this process requires increase in levels of intracellular calcium and cAMP, both of which are readily influenced by PEMF’S.

The observation of newly formed bony trabaculae lateral to the premaxillary suture in the area of tension may have been caused by a mechanism similar to that seen in the healing of non-union fractures by PEMF stimulated osteogenesis. The PEMF is thought to cause increased localized calcium deposition, which neutralizes the tissue net negative charge and allows for subsequent vascular invasion and the initiation of the sequence of osteogenesis.

The daily incremental pattern of tooth movement which showed an initial rapid movement followed by a lag phase and then a gradual increase through the remainder of the study is similar to that seen in humans. The initial rapid movement is due to the compression of the periodontal ligament and the elasticity of bone which bends a bit under force. The lag phase can be attributed to the periodontium trying to adapt to the force applied. Finally the remodeling process, in response to the continuous force application, brought about by osteoblastic and osteoclastic activity which gradually increased with more number of osteoclasts and osteoblasts being recruited to the remodeling site.

When a dynamic magnetic (i.e. an expanding –collapsing or time varying) field
passes through a static conductor, an electric current flows in the conductor. This is an example of inductive coupling and is the main principle behind the apparatus used to generate PEMF’s.

The PEMF’s are developed by a pulse generator supplying a time varying current to a pair of coils mounted on the external surface of the tissues to be stimulated. The PEMF’s or B field expands outward in space at right angles from the faces of the coil and penetrates the tissue. The magnitude of the induced current is determined, in part, by the driving voltage applied to the coils by the pulse generator.

Concern might be expressed about the induction of neoplasms as cell proliferation is enhanced. This has not been demonstrated in clinical or laboratory studies with PEMF’s. The predominant effect appears to be at the cell membrane through activation of cytosolic processes leading to increased proliferation without affecting the process of DNA replication itself.

In 1977, a hypothesis was advanced that pulses can be designed to evoke specific biologic responses. The pulse may vary not only in primary frequency but also in amplitude and harmonics. As induced pulse characterization has gone forward at the tissue level, it seems that different tissues may well "process" a given driving pulse in different ways. Based on frequency analysis of induced wave forms, it appears probable that the responses are tissue specific.

Continuous PEMF stimulation failed to enhance collagen synthesis compared to shorter intermittent exposure periods followed by rest periods outside the field. This observation that Pemf effects continue well after the pause suggest that, in vivo, PEMF may affect an early critical chemical event in the biologic process leading to the observed proliferation or differentiation. In the present study, the animals were exposed to PEMF’s for a period of 8 hours per day.

The animals selected were 9-10 weeks old at the start of the study, an age which is much higher than the 35 day old animals used by Stark and Sinclair. This was done deliberately to see if the PEMF’s could stimulate increased rate of orthodontic tooth movement in adult animals. Besides, at this age the premaxillary suture is definitely closed, as Storey reports that by 35 days the premaxillary suture is usually closed. Thus any laterally applied force to the central incisors should result primarily in biologic tooth movement and produce little or no opening of the premaxillary suture.

Although both direct current and PEMF’s appear to have the ability to stimulate increased rates of tooth movement, it is reported that direct currents do not penetrate the cell but cause electrochemical changes in the cell membrane. The PEMF produced pulsating current, on the other hand, are capable of penetrating the cell membrane and these stimuli could act either at the level of the cell membrane or directly affect intracellular organelles. They may, in fact, be more effective in eliciting a biologic response.

However, the main advantages of the PEMF’s are:

1. The complete non-invasiveness of the technique
2. The ability to alter the PEMF pulse characteristics to achieve specific cellular effects.
3. The absence of faradic reactions that are potentially tissue damaging, and

---

46  Journal of Dental Sciences and Research
4. The ability to generate a predictable current through a more efficient and less cumbersome apparatus.

These factors may serve to enhance its potential for further study with ultimate clinical application.

**SUMMARY AND CONCLUSIONS**

This study was done to determine whether the application of noninvasive pulsed electromagnetic fields could increase the rate and amount of orthodontic tooth movement in young adult guinea pigs.

Laterally directed orthodontic force was applied to the maxillary central incisors of a sample of twelve guinea pigs, divided equally into experimental and control groups, by means of a standardized intraoral coil spring inserted under constricting pressure into holes drilled in the maxillary central incisors.

The experimental animals were housed in acrylic animal holders and exposed to an area of uniform pulsed electromagnetic fields for eight hours per day for ten days. The control animals were similarly housed but not exposed to the pulsed electromagnetic fields.

The pulsed electromagnetic field device was composed of a pulse generator controlling a driver unit which in turn was connected to a pair of coils in Helmholtz configuration. The unit was adjusted to produce a pulsed magnetic field of 100 Hertz frequency and a peak magnetic field strength of 1.16 milli Tesla. The unit was powered by a 12 volt 2 ampere regulated power supply plugged into the mains outlet.

The experimental group animals showed significantly increased rates and amounts of orthodontic tooth movement from the 4th experimental day onward. They also showed increased amounts of bone deposition with orderly arrangement of the bony trabaculae. Increase in cellular activity was reflected by the presence of highly significant increase in the number of osteoclasts in the alveolar bone surrounding the maxillary central incisors of the experimental animals.

The results of this study support the premise that the rate of orthodontic tooth movement and amount of bone deposition can be enhanced through the application of a noninvasive pulsed electromagnetic field and may have potential future clinical use in the acceleration of orthodontic tooth movement.

**Bibliography**

1. Yasuda I
2. Norton L. A.
3. Stark T. M, Sinclair P. M
4. Davidovith Z
   The production of cyclic AMP by orthodontic forces Am. J. Orthod 1973; 64: 314
5. Norton L.A.
   Implications of bioelectric growth control in orthodontics and dentistry Angle Orthod 1975; 45:34 -42
   Bone growth in organic culture modified by an electric field. J. Dent. Res. 1972; 51: 1492 – 1499
D.N.A synthesis in cartilage cells is stimulated by oscillating electric fields. Science 1978; 199: 690 – 692
8. Shteyer A, Norton L.A. Rodan G. A
Electric currents, bone remodeling and orthodontic tooth movement (1) the effect of electric current on cyclic nucleotides. Am. J. Orthod 1980; 77: 14 – 32
11. Brighton CT, Alder S, Black J, Itada N, Friedenburg ZB
12. Yamasaki K
13. Bassett CAL
The development and application of pulsed electromagnetic field for ununited fractures and arthrodeses. Orthop Cl North Am 1984; 15:61 – 87
15. Storey E
16. Bassett CAL, Pawluk RJ, Becker RO
Effects of electric currents on bone in vivo. Nature 1964; 204: 652 – 654