EFFECTS OF CONTINUOUS MAGNETIC RADIATION UPON INCISOR ERUPTION *IN VIVO*

by

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Submitted in partial fulfillment of the requirements

for the Degree of Master of Science

Department of Orthodontics

School of Dentistry

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(Chairman)

Date MAY 25, 1979

EFFECTS OF CONTINUOUS MAGNETIC RADIATION UPON INCISOR ERUPTION RATE IN VIVO

Abstract

by

NED I. RIEGEL

From the variety of experiments carried out to date with regard to the process of tooth eruption, it seems that no single factor can be identified as being specifically responsible for the forces that actually produce the eruptive movement. All biologic processes, including tooth eruption, are ultimately founded on a series of chemical reactions and the properties of molecules, and it is known that these can be influenced significantly by magnetic and electric field interactions. Since magnetic fields have a broad spectrum of effects, it is hypothesized that a relationship may exist, or at least can occur, between magnetic fields and the process of tooth eruption. To date, however, no support for this supposition exists in the literature. Accordingly, the purpose of the present investigation is to attempt to alter the rate of tooth eruption by the direct application of a magnetic field force to the formative tissue of a growing, erupting tooth in a laboratory animal. The rabbit was selected because this animal has continuously erupting incisor teeth, and should a magnetic effect occur, the rates and amounts would be readily measurable.

Nine rabbits received metallic implants in the central incisors to facilitate measurements of eruption. Each individual animal served as his own control, and three treatment phases were carried out: (1) control phase, (2) experimental phase, and (3) sham phase. Each rabbit was fitted with an aluminum (nonmagnetic) appliance containing two samarian magnets, producing a uniform horizontal magnetic field of 325 oersted approximately perpendicular to the long axis of the incisor root. Sham appliances having identical size, shape and weight were constructed for the controls period. The amount of tooth eruption was measured for each rabbit as the animal passed through a nine day treatment period (sham, experimental and control periods for each animal) with a two week rest period between each phase. The teeth were implanted and relieved from occlusion every three days in order to eliminate occlusal forces as a variable. A serial cephalometric radiograph was taken at this time to record the extent of eruption. At the start and finish of the treatments, tetracycline was injected to mark the amount of new tooth tissue deposition.

Construction and fitting of the appliances within a rabbit's tolerance level for the sham and experimental periods required great care. Even so, an eleven percent mortality rate occurred, probably due to secondary infections accentuated by the appliances.

Results of this study did not show a statistically significant difference attributable to magnetic force application. It could not be demonstrated that a homogeneous magnetic field of 325

oersted for a nine day duration, passed perpendicular to the formative portion of a rabbit incisor, has any measurable effect on the rate of eruption.

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DEDICATED

TO

Mr. and Mrs. Kenneth Riegel

My parents, who made my education
and this thesis possible.

and

Lela D. Riegel

My wife, who gave her moral support
and assistance never faultering even
in moments of gloom.

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INTRODUCTION

Over the past seventy-five years, many attempts have been made to elucidate the prime source of the forces initiating tooth eruption. A full understanding of the forces governing eruption will probably come from investigations of the periodontium and constituent tissues after the discovery of a means to directly affects the rate of eruption without mechanically manipulating the tooth. This knowledge must depend upon a discriminating model system with a high degree of accuracy.

It is unfortunate that little detail is known concerning the factors affecting eruption. No single factor at present has produced evidence for being solely responsible for the force of eruption. This may be the reason for the multiple, conflicting theories in the literature concerning the mechanism governing the rate of eruption. All such proposals to date are based on soft tissue or osseous changes.

The biological effects of magnetic fields are wide ranged. Magnetic fields are known to have effects in both plants and animals. Magnetic fields, for example, have been shown to influence the navigation of small animal movements and the orientation of some plant roots. In man, magnetic fields have been demonstrated to have effect on the healing process in both calcified and non-calcified tissues.

Tooth eruption is a biological process that has not been fully explained, as stated previously. All biological processes are ultimately founded on a series of chemical reactions, and chemical properties are determined by the arrangement and motion of the components comprising molecules which in turn are influenced by magnetic and electric field interactions. Consequently, it would seem profitable to study basic biological phenomena utilizing experimental electrical and magnetic fields. Because tooth eruption rate is governed by some unknown biologic process, which ultimately will involve electron and molecular charge and motion, it is not unreasonable to suggest that a magnetic field affecting the biologic processes might also influence the rate of eruption.

Since an attempt to create a variation in the rate of tooth erpution by application of a magnetic field has not been attempted to date, the present study was undertaken.

REVIEW OF THE LITERATURE

Tooth Eruption

Moyers (1973) defines tooth eruption as "the developmental process that moves a tooth from its crypt position through the alveolar process into the oral cavity and to occlusion with its antagonist." A more suitable definition for the purposes of the present study might be one which considers the movement without restriction on occlusion with an antagonist. This would allow the inclusion of such phenomena as eruption in compensation for occlusal and mesial attrition, and supereruption due to lack of antagonist or retarded antagonist eruption. Sicher and Bhaskar (1972) handle this by designating three phases of eruption: "(1) preeruptive phase, (2) prefunctional eruptive phase, and (3) functional eruptive phase."

The term eruption shall be referred to in this paper as the process by which formed and forming tooth structures migrate from within the alveolar process.

The source of the forces of eruption are unknown to date. Eruption mechanisms have been proposed and debated for years. Sicher and Bhaskar (1972) suggested pulpal growth acting through a suspensory "hammock" ligament as a source of eruptive force. They postulated that the "intermediate plexus" of the periodontal ligament undergoes compensatory growth adjustments. Sicher observed such a plexus as early as 1923.

Shumaker (1960) found that the eruptive movements and root lengthening do not correlate closely. Gowiel confirmed this in 1961. Gowiel found rat incisors to continue eruption even when the roots were experimentally destroyed. Garn (1962) postulated that both the sequence and timing of eruption seemed to be genetic in nature.

Enlow (1975):

> ...proposed that the actual source of the propulsive mechanical force that brings about the eruption, vertical and horizontal drift, and other tooth movements is provided specifically by an abundant population of actively contractile fibroblasts ("myofibroblasts") on the resorptive sides of the socket.

Roberts (1971) proposed the total fundic tissue pressure as a force of eruption. By varying the pulpal pressure he attempted to change the rate of incisor eruption. The data did not statistically substantiate this theory.

It would seem no single factor is responsible for the force of eruption. At best, only a vague knowledge of the mechanism of eruption presently exists.

Magnetic Fields

The observation of magnetism originated with the discovery of naturally-occurring "stones", magnetite, and their ability to attract iron. Oersted (1820), by observing that a current flowing through a conductor produces a magnetic field, first related an electron flow with a magnetic field. Faraday (1831) was the first to present a visualizable description of a magnetic field and its

properties by conceptualizing lines of force. It took Maxwell (1861) to successfully describe electromagnetic fields utilizing mathematical equations. Since the first quantification of magnetic fields, researchers have discovered a wide variety of effects produced by magnetic fields in both the plant and animal kingdoms.

Biological Effects of Magnetic Fields

Lengyel (1932) conducted the first investigations on biological effects of static fields on tissue cultures. She used growing chicken heart tissues in vitro and found that the argyrophil fiber system was retarded and deformed during tissue growth.

Barnothy (1948) studied the effects of static magnetic fields upon the development of young mice. Using a relatively strong field of 5900 Oe[1] he monitored the development of the mice by weight. The magnetic field was found to retard the growth of the animals. A "cumulative lethal effect" was observed in one male mouse. It was proposed that the mechanism was due to a general retardation of mitotic activity in general. Later studies also uncovered a lengthening of the gestation period of pregnant mice when subjected to magnetic fields.

Barnothy (1948) conducted similar experiments on mice and confirmed the previous data. She found that the effects of a

[1]Oe =1 Oerstred = the cgs electromagnetic unit of magnetic intensity equal to the intensity of a magnetic field in a vacuum in which a unit magnetic pole experiences a mechanical force of one dyne in the direction of the field. A unit pole--a magnetic pole that will repell an equal and like pole at a distance of 1 cm. in a vacuum with a force of one dyne. 1 Gauss in a vacuum equals one Oerstred.

homogeneous field of 4200 Oe, with a field gradient of 80 Oe/cm., is far greater than an inhomogeneous field of 3600 Oe with aa field gradient of 650 Oe/cm. Her studies provide an explanation for the variability of results from other experimentation. She pointed out that it was not only the field strength but also the field gradient and its uniformity that could influence the effects.

Barnothy (1948) postulated the effects of magnetic fields on tumor-bearing animals as follows:

> ...it would isolate the tumor and prevent a spreading through migration of tumor cells; it would retard or arrest the growth of the tumor at a field strength which is not harmful to healthy tissues; and, finally, by increasing the lifespan it would provide time for the probably existing defense mechanisms of the body to fight the tumor.

He found that in field strengths of 2400 Oeto 4500 Oe a rejection of homotransplanted tumors of T2146 adenocarcinoma can be expected in 20 to 80% of cases and in field strengths of 4200 Oe with a .12 M Oe^2/cm gradient strength a lengthening of lifespan of mice with isotransplants occurred. The results suggest several basic reasons, such as a decrease of mitotic activity, a retardation and disorientation of the fibrous network the tumor grows along, or a change in the immunologic reaction of the host. Barnothy felt that immunologic reactions merited further investigations.

Barnothy (1956) studied the effects of a vertical homogeneous magnetic field of 4200 Oe. She found a decrease in the leukocyte count of 20 to 40% within the first two weeks followed by a rebound and subsequent increase in leukocytes. This is followed by a second drop in leukocytes reaching a minimum in approximately

thirty days. The explanation lies in the storing of leukocytes and the physiologic mechanism of compensation. Once these storage reserves are depleted then the inhibition of blood-forming elements is manifest.

Gross (1956) demonstrated that pretreatment with magnetic fields lengthens the life expectancy of tumor-bearing hosts. He suggested that this was due to the rebound of leukocytosis following pretreatment and its accompanied leukopemia. Gross postulated that these same mechanisms might also affect the healing process.

Gross and Smith (1964) proceeded to study the effects of a 3000-4000 Oe field with a 500 Oe/in gradient on wound healing and tissue regeneration. Using mice as a model they checked healing via fibroblast proliferation. The fibroblastic proliferation was markedly delayed by the magnetic field. The inhibition of the enzymatic production of large protein molecules and other biological polymers could account for these effects.

Haberditzl (1967) experimented with L-glutamic dehydrogenase (GDH) and catalase in both uniform and non-uniform fields, in vitro. He used field strengths from 50 to 78 k Oe. The GDH activity was inhibited in the uniform field and was inhibited even further by the non-uniform fields. Catalase showed an appreciable increase in both fields with the greatest effect in the non-uniform field. The unexpected increase in activity was thought to be a secondary effect of accelerated oxygen removal.

Whish (1963) devoted his efforts to the plant kingdom.

Using a 4000 Oe and 7100 Oe field he was able to demonstrate the orientation of Cress roots, oat coleoptiles and Phycomyces sporangiophores in a direction down the magnetic gradients. The plant responses were statistically greater for those of the 7100 Oe field compared with those of the 4000 Oe field. The magnetic fields used in these experiments are of a magnitude many fold larger than those fields generated by the earth's magnetic field. The geomagnetic field is approximately .17 Oe with continual fluctuation.

Pittlman (1962) while studying the geomagnetic effects on the roots of winter wheat noted a predominantly north-south orientation of the roots. He later found that some cereal crops germinated faster and grew larger when oriented longitudinally parallel to the lines of force rather than when oriented horizontally at right angles to those lines of force. In testing winter wheat the speed of germination and the seedling growth were affected by pregermination exposures of dry seeds to an introduced magnetic field. The greatest notable results occurred when the embryo ends were oriented toward the north pole of the induced magnetic field and later germinated with the same end oriented toward the geomagnetic north pole. Similar findings by other investigators support the findings of Pittlman.

Geomagnetic effects have been demonstrated in animals by Barnwell and Brown (1959) using a 1.5 Oe field:

> The mud snail, can respond to a horizontal magnetic field only about nine times stronger than the earth's field. It indicated that the snail can distinguish parallel from right-angle horizontal orientations of this field relative to its body axis.

More recently, using fields greater than geomagnetic strength but still relatively weak, Nahas, Boccalon, Berryer and Wagner (1975) studied the adverse effects of continuous exposure to those fields. The results indicated no toxic or histopathological effects on rats of 200 to 1,200 Oe fields. An unexpected increase in body and organ weight of young rats exposed to the magnets was seen following a one month exposure.

The effects of a magnetic field also encompass calcified tissues. Any conductor carrying a current will produce a field about the conductor according to Maxwell's equations. Norton and Moore (1972) utilized wire grids to modify cultured bone growth in an electric field. Using rat calvaria they found that the bones grow vertically in a strong field, arborize, and show a distortion of growth pattern. They postulated that a cast with an electric field generating capacity might be used for treatment of skeletal deformities during growth.

Bassett, Pawluk and Pilla (1974) used low-frequency pulsing electromagnetic fields on canine osteotomy sites. The magnetic field was inductively coupled across the skin directly to the bone. This procedure enhanced the repair of the osteotomies and after a 28 day period the bone appeared more organized and stronger than the control sites.

These same workers in 1973 proceeded to apply the pulsed electromagnetic fields to 29 human patients with pseudoarthritic joints or non-healing fractures who had been treated previously by one or more unsuccessful surgical attempts at bone repair. In most

cases amputation was advised by at least one qualified orthopedist prior to the new modality of treatment. The magnetic field was aligned perpendicular to the long axis of the fractured bone in the area of the pseudoarthritic joint. The overall success rate was in excess of 70% which included patients treated with inadequate pulse characteristics and those with poor cooperation. This simple non-surgical, out-patient method for healing pseudoarthrosis and non-unions may change the indications for amputations of surgically resistant cases.

In a follow-up study by Bassett and co-workers (1976) the overall success rate was increased to 85% by using two electromagnets strapped on opposite sides of the fracture area. Today an increasing number of clinical centers are being established to widen the availability of this method. At present, Dr. Richard Kaufman of Cleveland is using Bassett's devices in the treatment of fractures.

The exact mechanism of action of the magnetic fields upon the fracture is still unknown. Dramatic effects have been demonstrated on a wide variety of models with various magnetic fields. It is not unreasonable to assume that an effect on tooth eruption rate might also be seen. The exact mechanism of eruption also evading explanation at present makes the problem more complex. Whether the source of eruption rests in the hard structures or soft tissues is presently still debated, as previously noted. It is the intent here to treat this model as a black box and examine the data for an effect.

METHODS AND MATERIALS

General Description

The present study tested the effects of a magnetic field on the rate of mandibular incisor eruption of the rabbit. Nine New Zealand white male rabbits, six months of age, were used. Each rabbit had a complete dentition and initially weighed from 5.5 to 6.6 pounds. In statistical terms, the mandible of each rabbit constituted two plots, the left and right incisors, for each of the three phases--experimental, sham and control. Each animal thus served as its own sham, control and experimental model in this longitudinal study. Three animals were initially assigned at random to each of the three phases allowing all phases to run simultaneous. Each phase was of nine day duration with a two week rest before the rabbits were placed in the next phase (Table I).

All animals were implanted in the lower border of the mandible, as described below, using a wire loop implant technique. The mandibular incisors were also implanted using an amalgam in burr holes, and reduced from occlusion in order to allow uninhibited incisor eruption. A lightweight non-magnetic appliance was fitted to the rabbits' head to hold in place the permanent magnets and dummy magnets for both the experimental and sham phases, respectively. A horizontal magnetic field of approximately 325 oersted was established across the formative area of the lower incisors for the experimental phase. For the control group, no magnetic fields or

TABLE I

TREATMENT ASSIGNMENTS

Rabbits	Phase I	Phase II	Phase III
1 2 3	Experimental	Control	Sham
4 5 6	Sham	Experimental	Control
7 8 9	Control	Sham	Experimental

appliances were used. For the sham group, appliances fitted with dummy magnets were used. The amount of tooth eruption for each animal was measured from serial radiographs taken over a 16 week period at intervals of three days. Tetracycline injections for tooth labelling were given at the start and stop of each phase with the exception being at sacrafice. A histologic examination of a representative sample of incisors was carried out to compare relative amounts of tooth structure deposited during the different phases of the procedure. Statistical analysis of each phase was carried out by a three X two factorial analysis of variance test. Paired t-tests were also calculated.

Experimental Procedure

Anesthesia

The rabbits were first anesthetized by a combination of three drugs (Plate I). ROMPUM xylazine (Bayvet Corporation, Shawnee, Kansas) was administered intramuscularly, at a dosage of 5 mg. per kg. body weight, five minutes prior to the intramuscular injection of the second and third drugs. One cc. Acepromazine Maleate (10 mg.) (Ayerst Laboratories Inc., New York, New York) was combined with 10 cc of KETASET ketamine hydrochloride (1000 mg.) (Bristol Laboratories, Syracuse, New York). This combination was administered intramuscularly at approximately 35 mg./kg. of Ketaset and approximately .318 mg/kg. of Acepromazine. After about five minutes the animals had become sufficiently anesthetized for any of the procedures required in this study. The duration of anesthesia was approximately one hour.

PLATE I

Drugs used for Anesthesia


KETASET
Rompun

Surgical Implantation

After anesthetizing the animals their chins were shaved and cleansed prior to surgery. Surgical exposure of the inferior border of the mandibular left corpus was achieved through a ½ centimeter longitudinal incision at a location ½ a centimeter posterior to the symphysis. Using a ½ round burr rotated with a dental high speed handpiece, a hole was drilled through the labial and lingual cortical plates just superior to the inferior border of the corpus at a location in the area of the incision (Plate II). A .010 inch 300 series stainless steel dead soft orthodontic ligature wire was passed through the hole and the ends twisted together (Plate III). The periostium was closed with 4-0 chromate resorbable sutures. The skin was closed with 4-0 silk sutures which after healing were removed. The purpose of this wire was to provide a radiographic marker, since the cortical bone of the rabbit's mandible is too thin to hold a standard metallic implant using a Bjork implant punch.

Tooth Implantation

Implants were placed in the mandibular incisor teeth to determine amounts of eruption. The animals were first anesthetized in the manner previously mentioned and the left mandibular incisor then drilled from the labial with a ½ round dental burr. Care was taken not to heat the tooth and to drill the hole lateral to the pulpal chamber as close as possible to the gum level (Plate IV). The hole was filled with a mixture of Concise (3 M Company, St.

PLATE II

Surgical exposure for osseous implantation



PLATE III

Placement of osseous implant

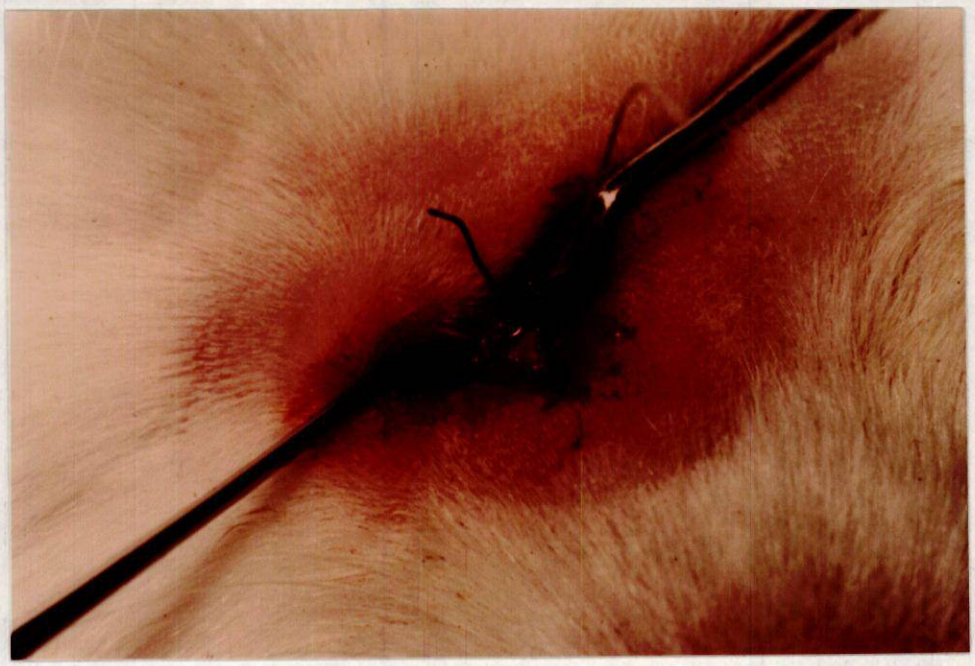
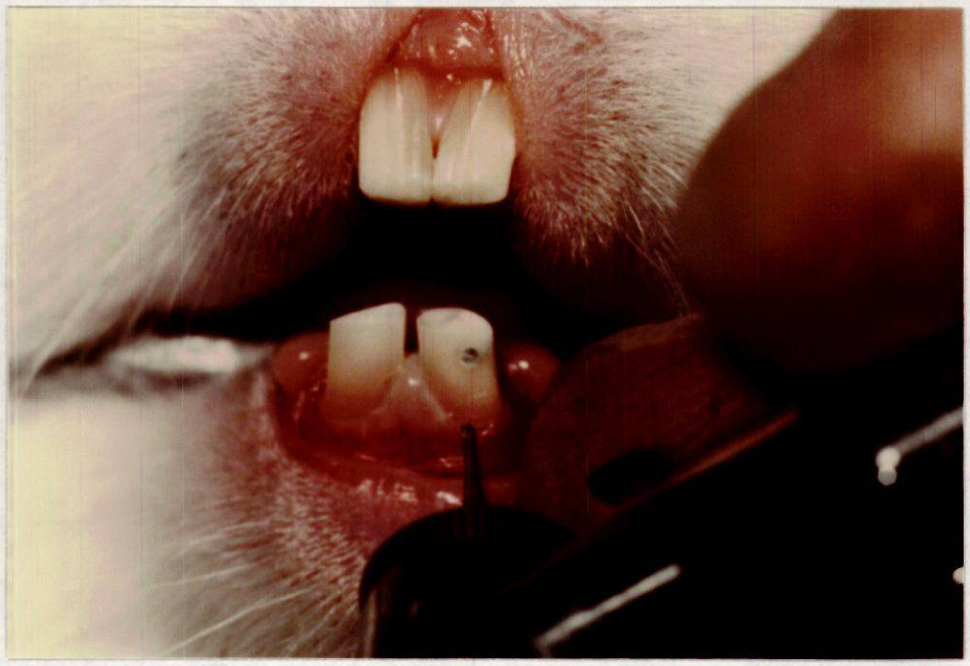


PLATE IV

Placement of tooth implant



Paul, Minnesota) and Dispersalloy (Johnson and Johnson Co., New Brunswick, New Jersey) amalgam filings. The Concise and amalgam used were both non-magnetic. The right mandibular incisor was prepared in a similar manner from the lingual surface in order to differentiate left from right radiographically.

The mandibular incisors were then reduced from occlusion as far as the implants would allow without their loss. The maxillary four incisors were reduced occlusally to the physical limits, the free gingival margin, with a high speed diamond bur (Plates V, A and B). Due to the rapid rate of eruption it was necessary to grind the incisors every three days to prevent occlusal interferences during the three phases of the study. At the end of a three day period the rabbits were anesthetized and new implants fixed in the teeth. A radiograph was taken and the teeth then reduced from occlusion. This related the new implant position to the old, now ground away, implant. The procedure was repeated every three days until the end of the phase at which time only a radiograph was taken.

Post Operative Procedure

Magnetic Field Generator

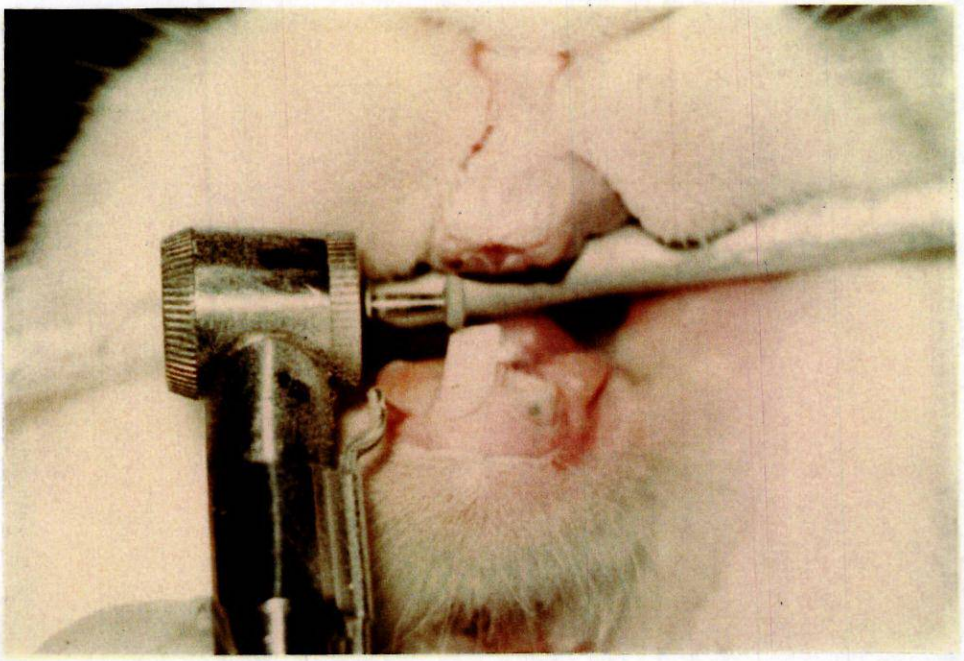
Each of the experimental appliances was fitted with two Samarium cobalt alloy magnets having dimensions of 1" x 1" x ¼" (Edmund Scientific Co., Barrington, New Jersey) with opposite poles facing one another toward the midline. By placing the magnets at the level overlying the germinal part of the incisors, a

PLATE V A

Method of occlusal reduction

PLATE V B

Occlusal reduction completed





uniform magnetic field was thereby produced in the area of the mandibular incisor formative ends. The magnitude of the field was approximately 325 oerstead. The field measurements were made with a Bell 120 Gaussmeter utilizing the Hall effect. The magnets were attached to the framework used to support them on each rabbit's head with EPOXE ribbon (Loctite Corporation, Cleveland, Ohio). The magnets were orientated with the north pole closest the right side and the south pole closest the left side of the rabbits head. The interpolar distance was established at 57.0 mm. The supportive framework was constructed entirely from aluminum, leather, and other non-magnetic materials. All supportive parts were padded with 5/16 closed cell foam and fitted to each individual rabbit (Plate VI). It was necessary to use an elastic strap under the chin as well as a leather collar about the neck to prevent the rabbits from rejecting the appliances.

Sham Appliances

The sham appliance frameworks were constructed identical to the experimental frameworks. The magnets were replaced by stainless steel shams having identical size and weight. The shams were affixed with brass rivets rather than the epoxy ribbon, due to ease of drilling the stainless steel shams and for greater strength.

Tetracycline Markers

Tetracycline hydrochloride (Rachelle Labs Inc., Long Beach, California) was administered intramuscularly at the start and finish of each phase. It was given at a dose rate of 85 mg per

PLATE VI

Magnetic appliance



rabbit. This provided adequate staining lines in the teeth for use as fluorescent growth markers (Plate VII).

Care and Feeding

The animals were housed separately in non-magnetic 300 stainless steel cages to eliminate interactions with other metals (Plate VIII). They were fed Purina rabbit chow (Ralston Purina Company, St. Louis, Missouri) and allowed water ad lib. The animals were kept in individual cages housed in a thermostatically controlled room at 69° ±1° F. Lighting was controlled such that the rabbits were subject to 12 hours of light and 12 hours of darkness for each 24 hour period.

Control Phase

The rabbits during the control phase were anesthetized and implanted the same as in the experimental and sham phases. Tetracycline was administered in the same manner and timing as the experimental and sham phases. The rabbits did not wear any type of appliance during this period but were treated the same in every other respect as during the sham and experimental phases.

Cephalostat

A head holding device was designed to permit reliable reproducable positioning of the mandible for serial radiographs. The source object distance was established at five feet and the object film distance was constant for a given animal (Plate IX).

The head of the rabbit was held securely by placing an occlusal table between the anterior and posterior teeth. The

PLATE VII

Tetracycline tooth banding

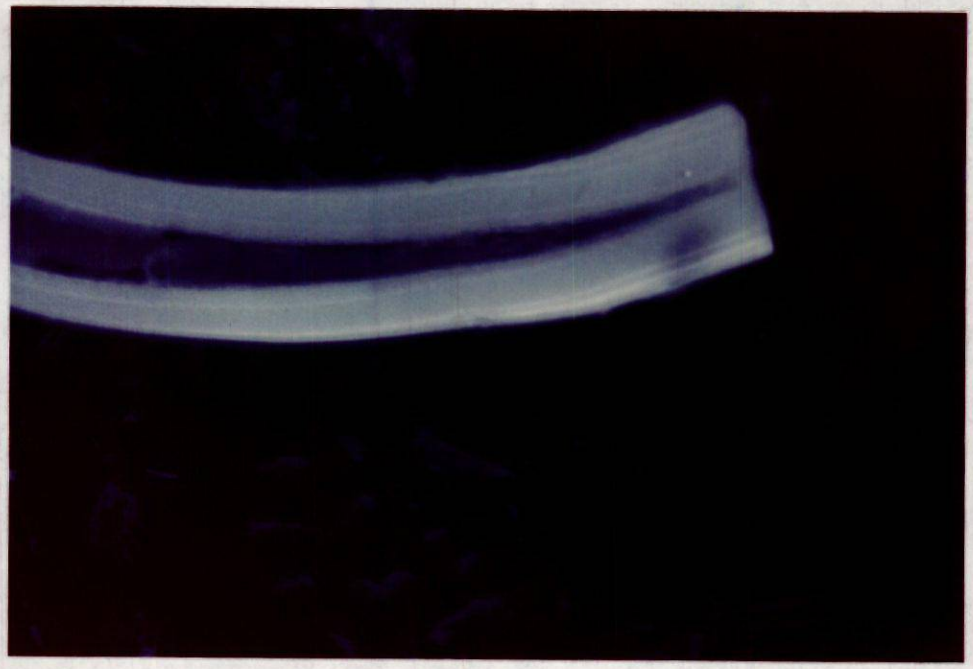


PLATE VIII

Animal cages

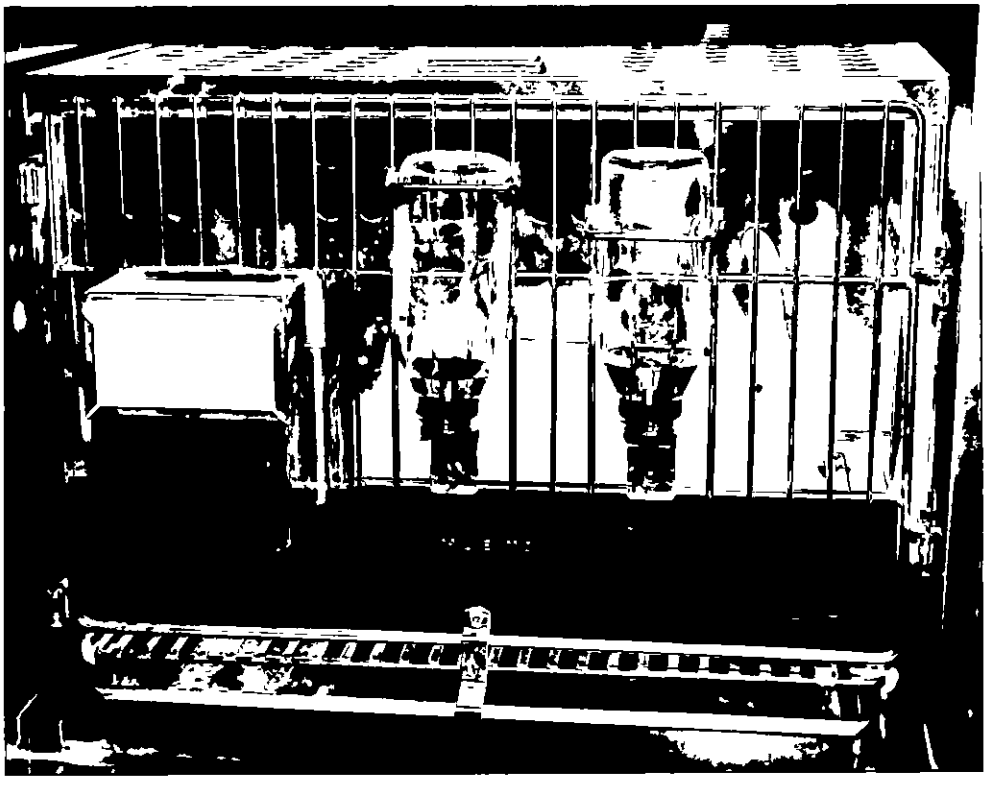


PLATE IX

Cephalometric apparatus



midsagittal plane of the head was kept perpendicular to the central ray and parallel to the radiographic film. A 2½" x 3" occlusal film (Kodak Corporation, Rochester, New York) was used. All exposures were taken at 80 kvp, 10 mA, and 3 seconds.

Post Operative Evaluation

The animals were maintained until all three phases were complete. At that time they were killed with an overdose of sodium pentobarbitol. A final roentgenograph was taken, and the mandibles were then dissected for future histologic preparation of the teeth.

Cephalometric Measurement

The amount of incisor eruption was determined by measurements of the implant locations taken from exact three to one photographic enlargements of the radiographs (Plates X and XI). The first in a series of photographs was measured from bone marker to labial implant and then transfered precisely to the second photograph in the series using a Helios calipers. An arc was scribed on the second photograph across the tooth using the bone implant as a reference point. This was done for both the labial and lingual implants. The measurement taken was that from the scribed arc intersection with the lingual margin of the tooth to the corresponding tooth implant's new position (Figure 1). Thus, a recording of the eruption distance movement was determined for each tooth from the third, six, and nine day photographs of each phase. The simple total of the three measurements yielded the total extent of eruption during the nine day period.

PLATE X

Cephalometric radiograph

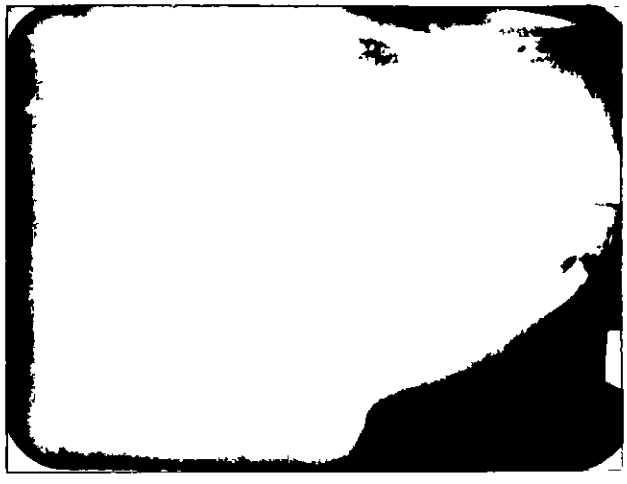
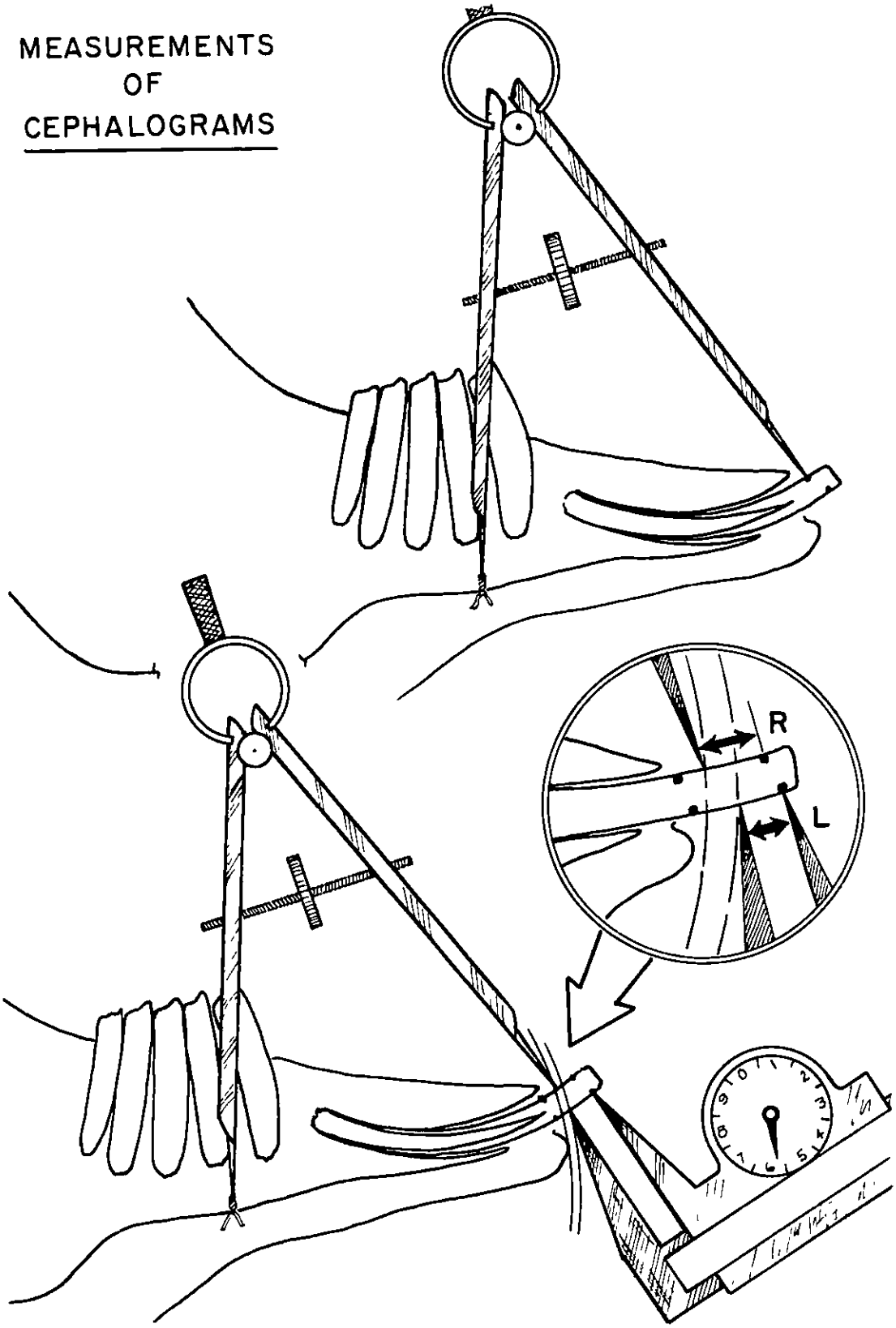


PLATE XI

Three to one print of cephalometric radiograph

Figure 1. Cephalometric measurement technique.

MEASUREMENTS
OF
CEPHALOGRAMS



Histologic Evaluation

At the termination of the procedure, the mandibles were removed and fixed in buffered formalin (Plate XII). Through careful dissection each entire incisor was then removed and sectioned precisely down the center of the pulp chamber (Plate XIII). These sections were then polished and examined under U.V. light of 390 nm. A microscope reticule calibrated to 42 lines per millimeter was used to measure band spacing perpendicular to the long axis of the tooth.

Data Reduction

Since each rabbit has its own rate of incisor eruption, every animal was evaluated separately for each plot (phase). The plots could not be tested simultaneously on the same animal; therefore, the animals were randomly divided into three groups of three. Through a rotation of plots all the animals were subjected to every plot, thus a three phase crossover design was established.

The data was analysed by a three X two factorial analysis of variance test. Paired t-tests were used to account for the same rabbit being used in all three phases.

PLATE XII

Mandible preparation

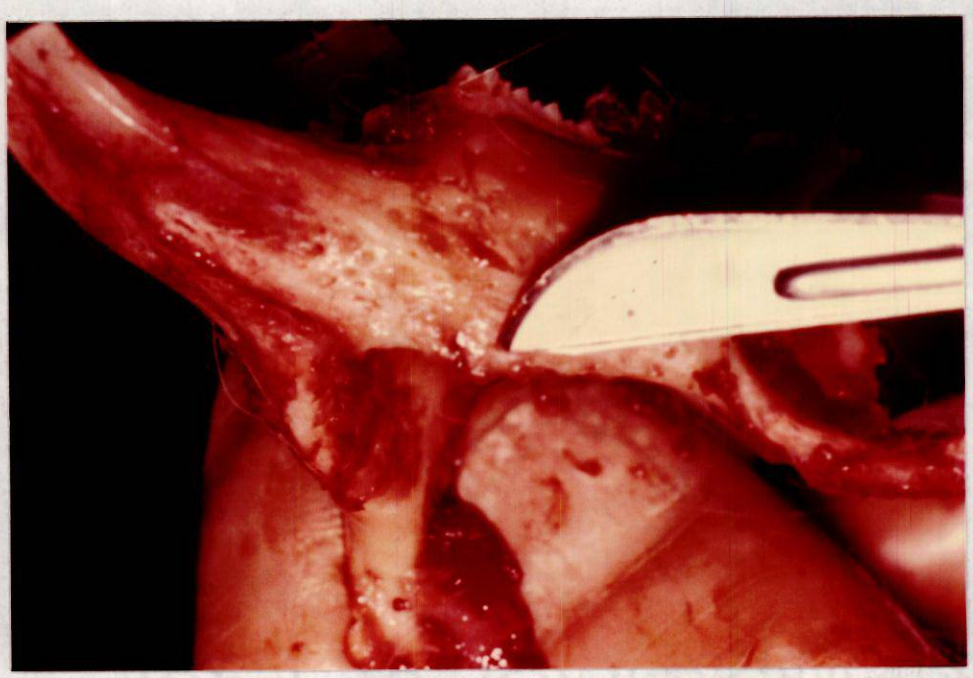
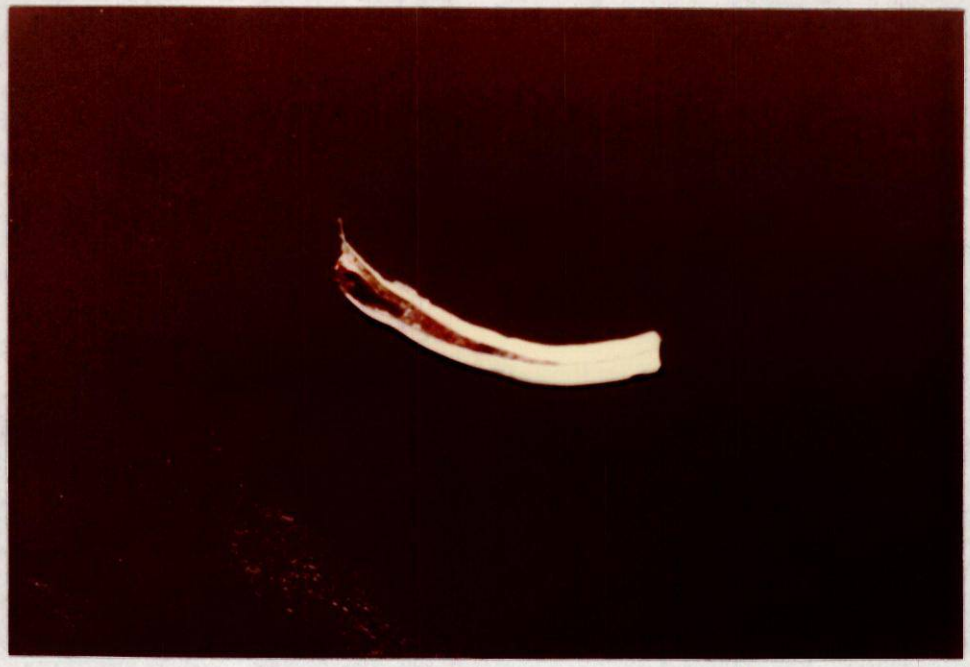


PLATE XIII

Tooth preparation



RESULTS

Serial Radiographic Measurements

The amount of tooth eruption occurring during each of the nine day phases for each rabbit is presented in Table II. The amount of eruption of the right tooth with the lingual implant was found to be consistently less than that of the left tooth with labial implant for every phase, but this is due to the normal curvature of the erupting tooth rather than the experimental procedure itself. One exception to this trend is the interpolated data on rabbit #2 during the sham phase. No apparent trends can be seen between the three treatment phases (sham, experimental and control) when comparing the corresponding teeth.

Descriptive Statistics

Means (X) and standard deviations (SD) are presented in Table III. A trend is apparent in that the control eruption mean is slightly larger than both the sham mean and experimental mean. The sham and experimental mean were approximately equal. The right tooth (lingual implant) eruption was less than the left tooth (labial implant) eruption, as noted previously.

Inferential Statistics

The results of the three X two factorial analysis of variance test for the three phase crossover design are presented in Table IV. The null hypothesis could not be rejected when con-

TABLE II

NINE-DAY ERUPTION (mm.)
INDIVIDUAL DATA

Rabbit	Control		Sham		Experimental	
	Labial Left Tooth	Lingual Right Tooth	Labial Left Tooth	Lingual Right Tooth	Labial Left Tooth	Lingual Right Tooth
1	17.21	15.16	16.52	12.91	14.12	12.69
2	16.62	16.44	14.52*	17.01*	15.53	13.30
3	13.83	11.44	14.73	13.25	11.09	8.45
4	15.37	14.55	15.18	12.56	10.78	11.83
5	13.31	13.26	16.20	15.57	15.25	14.99
6	15.27	12.79	14.43	11.28	15.68	13.70
7	14.06	9.87	13.48	10.77	16.10	11.03
8	17.87	14.60	12.62	9.52	16.01	14.51
9	15.32	12.20	12.12	12.08	13.64	11.90

*Interpolated from a three day run, death occurred at that time.

TABLE III

MEANS AND STANDARD DEVIATIONS
NINE-DAY ERUPTION (mm.)

	Labial or Left Tooth		Lingual or Right Tooth		Average	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
(1) Control	15.43	(1.56)	13.37	(2.04)	14.40	(2.06)
(2) Sham	14.42	(1.49)	12.77	(2.33)	13.60	(2.08)
(3) Experimental	14.30	(2.09)	12.49	(1.99)	13.39	(2.19)

TABLE IV

ANALYSIS OF VARIANCE

Source	df	SSQ	MSQ	F	P
Main Effects					
Treatment	2	10.144	5.072	1.350	0.268
Tooth	1	45.742	45.742	12.174	0.001
Interaction (Tx X Tooth)	2	0.386	0.193	0.051	0.999
Residual	48	180.357	3.757	* *	* *
Total	53	236.630	4.465	* *	* *

sidering the three treatment phases. The tooth differences, left or right, proved to be statistically significant but not treatment dependent. This appears to be attributed to the curvature of the tooth and implant location, as previously stated. The three treatments (sham, experimental and control) were not statistically different in the rates of eruption.

Paired t-tests ($p=.05$) were also performed in order to account for each rabbit rotating through each treatment phase. The results of the t-tests are presented in Table V. The only significant result ($p = .038$) was the experimental-sham vs. control test with the control ratio of eruption being greater than the experimental-sham eruption rate. This was probably due to a decrease in food intake caused by the wearing of the facial appliance during the sham and experimental phases.

Tetracycline Band Spacing

The results of the tetracycline band spacing are presented in Table VI. The sample size of the banding contraindicated further statistical analysis (see Discussion).

TABLE V

t-TESTS

Variable	Number of Cases	(Difference) Mean	Standard Error	t Value	2-Tail Probability
Control Experimental	18	1.0039	0.496	2.02	0.059
Control Sham	18	0.8011	0.537	1.49	0.154
Sham Experimental	18	0.2028	0.651	0.31	0.759
Sham-Control Experimental	18	0.6033	0.513	1.18	0.255
Experimental-Control Sham	18	0.2992	0.543	0.55	0.589
Control Experimental-Sham	18	0.9025	0.402	2.25	0.038

TABLE VI

TETRACYCLINE BAND SPACING (mm.)

	Control		Sham		Experimental	
Tooth	Labial	Lingual	Labial	Lingual	Labial	Lingual
3	0.15176	0.19047	0.14285	0.11904	*	*
6	0.11904	0.11904	*	*	0.19047	0.21428
9	*	*	0.26190	0.23809	0.07142	0.10714

* Due to the length of the study, these bands were ground off the tooth prior to completion of the study.

DISCUSSION

The purpose of this pilot study was to determine the possible effects of a 325 oersted magnetic field on the rate and amount of incisor eruption in the rabbit. The design of the study regarded the intrinsic mechanism of tooth eruption as a black box in an attempt to find a factor that is involved in the control of eruption from which future studies might be able to determine the actual mechanism of eruption itself.

This investigation did not show statistically significant results with regard to rate and amount of eruption, and a discussion as to how and why this may have happened is presented. While the results show a significant difference in the rate of eruption between the left tooth, labially implanted, and the right tooth, lingually implanted, this may be due to the normal curvature of the lower incisors during eruption. The curvature of the teeth is due to the difference in rate of deposition of tooth structure between the labial and lingual portions of the teeth. An implant moving in an arc of smaller radius will be moved a shorter linear distance along such an arc than an implant moving in an arc of larger radius both moving the same number of degrees. Due to the placement of the implants, the difference in rate of eruption of labial and lingual implants only reflects the placement and not a difference in rate of eruption between the left and right teeth.

The appliance design was such that a uniform horizontal field could be created in the area of the formative portion of the lower incisors. The appliance was designed for greatest tolerance by the rabbits; but, even so, the sham and experimental appliances inhibited the intake of food. This was evidenced by the reduction in amount of food consumed and also by the reduced trend of root eruption in the sham and experimental animals as compared with the controls.

The field strength used was 325 oerstred, but no previous studies exist that might suggest a possible threshold level. The level of magnetic strength used in this study was determined primarily by ease of application. A field strength of comparable magnitude was sufficient to produce results in rats in the study of Nahas, Boccalon, Berryer and Bernard (1975) and yet not of such magnitude as to cause observably abnormal responses in the animals used. A much stronger field may be necessary in order to achieve results, and future studies should use a varying series of field strengths of larger magnitude. It is suggested that the magnetic field be oriented in a vertical direction and that a field generator be employed similar to that used by Barnothy (1964). The field strength threshold level may vary for the particular strain of animal used as well as the particular area tested.

Pulpal trauma was minimized but still existed from the cavity preparation of the incisor implants. Trauma to the teeth might affect eruption in the rabbits, but it was uniform in all treatments, including the controls.

Secondary infections of "snuffles" was a problem during the sham and experimental periods due to appliance design. Inflammation of the eyes occurred in all rabbits, and snuffles was the probable cause of death in eleven percent of the animals.

The results using the tetracycline growth markers were inconclusive due to the length of time involved in the study. The initial tetracycline bands necessarily became ground away before the animals were killed, and therefore only a maximum of two treatment bands could be compared. A future study designed to monitor the deposition of growing tooth structure should consider using a much shorter treatment duration.

The present study dealt specifically with the effects of magnetic fields on the rate of eruption. A variety of other studies dealing with piezoelectric effects and bioelectric responses associated with mechanical strain are present in the literature, but are not considered in this study.

SUMMARY AND CONCLUSIONS

From the variety of experiments carried out to date with regard to the process of tooth eruption, it seems that no single factor can be identified as being specifically responsible for the forces that actually produce the eruptive movement. All biologic processes, including tooth eruption, are ultimately founded on a series of chemical reactions and the properties of molecules, and it is known that these can be influenced significantly by magnetic and electric field interactions. Since magnetic fields have a broad spectrum of effects, it is hypothesized that a relationship may exist, or at least can occur, between magnetic fields and the process of tooth eruption. To date, however, no support for this supposition exists in the literature. Accordingly, the purpose of the present investigation is to attempt to alter the rate of tooth eruption by the direct application of a magnetic field force to the formative tissue of a growing, erupting tooth in a laboratory animal. The rabbit was selected because this animal has continuously erupting incisor teeth, and should a magnetic effect occur, the rates and amounts would be readily measurable.

Nine rabbits received metallic implants in the central incisors to facilitate measurements of eruption. Each individual animal served as his own control, and three treatment phases were carried out: (1) control phase, (2) experimental phase, and (3) sham

phase. Each rabbit was fitted with an aluminum (nonmagnetic) appliance containing two samarian magnets, producing a uniform horizontal magnetic field of 325 oersted approximately perpendicular to the long axis of the incisor root. Sham appliances having identical size, shape and weight were constructed for the controls period. The amount of tooth eruption was measured for each rabbit as the animal passed through a nine day treatment period (sham, experimental and control periods for each animal) with a two week rest period between each phase. The teeth were implanted and relieved from occlusion every three days in order to eliminate occlusal forces as a variable. A serial cephalometric radiograph was taken at this time to record the extent of eruption. At the start and finish of the treatments, tetracycline was injected to mark the amount of new tooth tissue deposition.

Construction and fitting of the appliances within a rabbit's tolerance level for the sham and experimental periods required great care. Even so, an eleven percent mortality rate occurred, probably due to secondary infections accentuated by the appliances.

Results of this study did not show a statistically significant difference attributable to magnetic force application. It could not be demonstrated that a homogeneous magnetic field of 325 oersted for a nine day duration, passed perpendicular to the formative portion of a rabbit incisor, has any measurable effect on the rate of eruption.

SELECTED LITERATURE CITED

Alt, F. 1963. Instrument Society of America, Vol. 1, New York: Phenum Press, pp. 95-156.

Audus, L. J. and Whish, J. C. 1964. Magnetotrophism. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M.F. (ed.). New York: Plenum Press, pp. 170-182.

Barnard, R. D. 1963. Biologic systems' magnetic susceptibility. In National Biomedical Insrumentation Symposium, Alt, F. (ed.). New York: Plenum Press, pp. 143-156.

Barnothy, J. M. 1964. Proposed Mechanisms for the Navigation of Migrating Birds. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 287-293.

Barnothy, J. M. 1964. Rejection of Transplanted Tumors in Mice. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 100-108.

Barnothy, J. M. 1964. Development of Young Mice. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 92-99.

Barnothy, J. M. 1964. The Vector Character of Field and Gradient and its Possible Implications for Biomagnetic Experiments and Space Travel. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 56-73.

Barnothy, M. F. 1963. Biological effects of magnetic fields on small mammals. In National Biomedical Instrumentation Symposium, Alt, F. (ed.). New York: Plenum Press, pp. 127-136.

Barnothy, M. F. 1964. Biological Effects of Magnetic Fields, Vol. 1. New York: Plenum Press, pp. 1-292.

Barnothy, M. F. 1969. Biological Effects of Magnetic Fields, Vol. 2. New York: Plenum Press, pp. 1-301.

Barnwell, F. H., and Brown, F. A. 1964. Responses of Planarians and Snails. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 263-278.

Bassett, C. A. L., and Pawluk, R. J. 1964. Effects of electric currents on bone in vivo. Nature, 204: 652-654.

Bassett, C. A. L., Pilla, A. A., and Pawluk, R. J. 1977. A non-operative salvage of surgically-resistant pseudarthrosis and non-unions by pulsed electromagnetic fields. Science, 124: 128-143.

Bassett, C. A. L., Pawluk, R. J., and Pilla, A. A. 1974. Augmentation of bone repair by inductively coupled electromagnetic fields. Science, 184: 575-577.

Baum, S. J., Ekstrom, M. E., Skidmore, W. D., Wyant, D. E., and Atkinson, J. L. 1976. Biological measurements in rodents exposed continuously throughout their adult life to pulsed electromagnetic radiation. Health Physics, 30: 161-166.

Beeson, D. C. 1973. The effects of electric currents on orthodontic movement in vivo. M. S. Thesis, Case Western Reserve University, Cleveland.

Beeson, D. C., Johnston, L. E., and Wisotzky, J. 1975. Effects of constant currents on orthodontic tooth movement in the cat. J. Dent. Res., 54(2): 251-254.

Beischer, D. E. 1964. Survival of Animals in Magnetic Fields of 140,000 Oe. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 201-208.

Blechman, B. S., and Smiley, H. 1978. Magnetic force in orthodontics. Am. J. Ortho., 74(4): 435-443.

Chikazumi, S. 1964. Physics of Magnetism. Translated by Stanley H. Charop. New York: John Wiley & Sons, pp. 3-108.

Cook, E. S., and Smith, M. J. 1964. Increase of Trypsin Activity. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 246-254.

Cooperman, L. L. 1965. An investigation into the possible application of magnetic forces to serve the needs of orthodontic procedures. M. S. Thesis, Columbia University, New York.

Cowgiel, J. M. 1967. Observations on the phenomena of tooth eruption. J. Dent. Res., 46(6): 1325-1329.

Craigie, E. H. 1966. A Laboratory Guide to the Anatomy of the Rabbit. Toronto: University of Toronto Press.

Craigie, E. H. 1957. Practical Anatomy of the Rabbit. Toronto: University of Toronto Press.

Daniel, W. W. 1974. Biostatistics: A Foundation for Analysis in the Health Sciences. New York: John Wiley and Sons, Inc. pp. 163-168, 205-215.

Enlow, D. H. 1975. Handbook of Facial Growth. Philadelphia: W. B. Saunders, Co., pp. 124, 351.

Gerencser, V. F., Barnothy, M. F., and Barnothy, J. M. 1964. Inhibition of Bacterial Growth in Fields of High Paramagnetic Strength. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 229-245.

Gross, L. 1963. The influence of magnetic fields on the production of antibody. In National Biomedical Instrumentation, Alt, F. (ed.). New York: Plenum Press, pp. 137-142.

Gross, L. 1964. Lifespan Increase of Tumor-Bearing Mice Through Pretreatment. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 132-139.

Gross, L., and Smith, L. W. 1964. Wound Healing and Tissue Regeneration. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 140-145.

Gullbault, G. G. 1973. Practical Fluorescence, Theory, Methods, Techniques. New York: Marcel, Dekker, Inc., pp. 4, 5, 324.

Gunter, R. C., Bamberger, S., Valet, G., Crossin, M., and Bauer, G. R. 1978. The trajectories of particles suspended in electrolytes under the influence of crossed electric and magnetic fields. Biophys. Struct. Mechanism, 4: 87-95.

Haberditzl, W. 1967. Enzyme activity in high magnetic fields. Nature, 213: 72-73.

Hackel, E., Smith, A. E., and Montgomery, D. J. 1964. Aggulutination of Human Erythrocytes. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 218-228.

Halliday, D., and Resnick, R. 1962. Physics, Vol. 2. New York: John Wiley and Sons, pp. 647-707, 815-991.

Jonnard, R. 1963. Peripatetic views on some premature biomagnetic investigations. In National Biomedical Instrumentation Symposium, Alt, F. (ed.). New York: Plenum Press, pp. 95-101.

Kholodov, Yu. A. 1964. Effects on the Central Nervous System. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 196-200.

Lavine, L. S., Lustrin, I., and Shamos, M. H. 1969. Experimental model for studying the effect of electric current on bone in vivo. Nature, 224: 1112-1113.

Mericle, R. P., Mericle, L. W., Smith, A. E., Campbell, W. F., and Montgomery, D. J. 1964. Plant Growth Responses. In Biological Effects of Magnetic Fields, Vol. 1., Barnothy, M. F. (ed.). New York: Plenum Press, pp. 183-195.

Montgomery, D. J., and Smith, A. E. 1963. A Search for Biological Effects of Magnetic Fields. In National Biomedical Instrumentation Symposium, Alt, F. (ed.). New York: Plenum Press, pp. 123-125.

Moyers, R. E. 1973. Handbook of Orthodontics, third edition. Chicago: Year Book Medical Publishers, pp. 166-239.

Mulay, I. L., and Mulay, L. N. 1964. Effects on "Drosophilia melanogaster" and S-37 Tumor Cells; Postulates for Magnetic Field Interactions. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 146-169.

Mulay, L. N. 1964. Basic Concepts Related to Magnetic Fields and Magnetic Susceptibility. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 33-55.

Nahas, G. G., Boccalon, H., Berryer, P., and Wagner, B. 1975. Effects in rodents of a 1-month exposure to magnetic fields (200-1200 Gauss). Aviat. Space Environ. Med., 46(9): 1161-1163.

Neurath, P. W. 1964. Simple Theoretical Models for Magnetic Interactions wth Biological Units. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 25-32.

Norton, L. A., and Moore, R. R. 1972. Bone growth in organ culture modified by an electric field. J. Dent. Res., 51(5): 1492-1499.

Osol, A. 1972. Blakiston's Gould Medical Dictionary, 3rd ed. New York: McGraw-Hill, p. 523.

Pittman, U. J. 1963. Effects of magnetism on seedling growth of cereal plants. In National Biomedical Instrumentation Symposium, Alt, F. (ed.). New York: Plenum Press, pp. 117-122.

Price, E. 1979. Bone fractures being healed with electricity. Cleveland: Plain Dealer, p. 10A.

Reno, V. R., and Nutini, L. G. 1964. Tissue Respiration. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 211-217.

Rocard, Y. 1964. Actions of a Very Weak Magnetic Gradient: The Reflex of the Dowser. In Biological Effects of Magnetic Fields, Vol. 1, Barnothy, M. F. (ed.). New York: Plenum Press, pp. 279-286.

Sicher, H., and Bhaskar, S. N. 1972. Orban's Oral Histology and Embryology. St. Louis: C. V. Mosby, pp. 298-315.

Weyman, J. 1968. The effect of irradiation on developing teeth. O.S., O.M., and O.P., 25(4): 623-629.

Whish, J. C. 1963. Plant Growth in a Steep Magnetic Gradient. In National Biomedical Instrumentation Symposium, Alt, F. (ed.). New York: Plenum Press, pp. 103-116.

Whitehouse, R. H., and Grove, A. J. 1947. Dissection of the Rabbit. Clifton House: University of Tutorial Press, L.T.D.

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