Treatment of Bone Repair by Inductively Magnetic Fields

Jae Mok Ahn, Woo Cheol Lee, Hee Chan Kim,
and Byoung Goo Min

Dept. of Biomedical Engineering,
Institute of Biomedical Engineering, College of Medicine,
Seoul National University

Abstract: An inductively coupled magnetical signal(pulse wave,0.7 to 60Hz,eighteen volts peak to peak) that was applied non-invasively on the skin surface overlying the approximate site(measure position). In the group with unipolar pulse signal currents produced smaller than in the group with bipolar pulse signal. The signal was transmitted to the active coil,including a time-varying magnetic field: this in turn induced a time-varying electrical field in the field in the bone. It is very important to determine system parameters due to treatment time(healing) and the simplicity. This paper investigation was designed to compare the relative effects of pulsed unipolar currents with the effects of an identical pulsed bipolar currents. Since inductive coupling is non-invasive and involves portable equipment,it is easy to apply and requires precise localization,it has distinct advantages and field characteristics along the bone for each different signal.

1. Introduction

The application of electrical energy to fractures may stimulate their healing. Implanted electrodes can be accurately. It is,however,difficult to determine the part played by electrical stimulation because of differing techniques of application and variations in the clinical content of the series reported in the literature. The purpose of this paper is to report a proper parameters and Gauss for treatment by both unipolar and bipolar magnetic stimulation. Before magnetic field(MF) treatment of non-unions in the human bone,we must describe that the effects of magnetic field in other animals(rabbits or dogs) can cause the callus which reforms bone fracture-sites. Thus,for the effects on the mechanical and histological repair properties of an osteotomy of the radius of the rabbits or dogs,we assayed different pulsing magnetic fields. Highly significant differences were found in the control and experimental inital load valus and their decay as a function of time. We think that these parameters correlate well with the histological pattern in the bridging callus. Particularly,system apparatus depends on the anatomical site and severity of the non-union. For example,the femur requires larger driving-voltage for desired Gauss than the tibia. The Gauss value of this paper is ranged from 100 to 400G. The electrical field(EF) driving at right direction to magnetic field(BF) is induced different value(1mV/cm to 100mV/cm) according to driving circuit pulses. As Gauss detectors,we used type UGN-3503U and UGS-3503U Hall Effect sensors which track extremely small change in magnetic flux density. This sensor is supplied in a three-pin plastic package only 61mils(1.54mm)thick. Type UGN-3503U is rated for continuous operation over the temperature range of -20 degree to +85 degree. Type UGS-3503U operates over an extended temperature range of -40 degree to +125 degree. In operation, proportional output-voltage levels are dependent magnetic flux density at the most sensitive are of the device(fig1). In this report, we can describe an advantages as follows;

1) not surgery
2) not infected
3) simple
4) easy procedures.

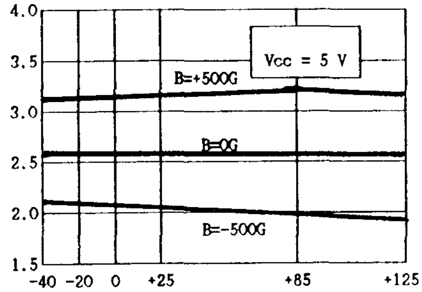


Fig 1. Output voltage as a function of temperature

2. Theory

<u>frequency choise</u>

The basic idea which includes electrical signal on applying mechanical stimulation to bone is important component for choosing driving frequency of bone repair. As above bone condition,we say that it is operated as transducing element which condition changes mechanical load to electrical signal. This is called remodelling of bone. In order to produce artifical remodelling. We apply to bone fracture signal wave form similar to the original wave form produced by deforming load. Therefore,the determination of signal wave form similar to natural wave form requires specific parameter values known as transfer function of bone transducer. In order to obtain transfer function of transducer (bone). Below processes must be followed.

$$V_o(t) = V_P(t)\ [K + (1-K)\exp(-t/\tau_2) - \exp(-t/\tau_1)$$

$$F(t) = \int_0^{\infty} e^{-st} F(t)dt$$

$$V_o(s) = V_P(s)\ [K/s + (1-K)/(s+1/\tau_2) - 1/(s+1/\tau_1)]$$

$$H(s) = \frac{V_o(s)}{V_P(s)}$$

$$H(s) = \frac{As + B}{(s^2+Cs+D)\cdot s} \times s$$

A=19.34 B=0.677 C=20.69 D=13.84

$s = j\omega \qquad \omega = 2\pi f$

V_o:output of transducer, V_P:peak voltage, K:dc multiplicative facter.

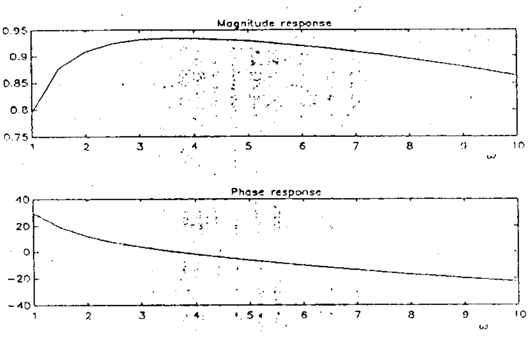


Fig 2. Maximum transfer function

<u>coil - driving circuit elements</u>

The determination of threshold voltage and current to stimulate osteogenesis must be required to know the mechanism of bio-electrical system in the bone. The effects of electrcal signal in the bone show well in the many literature. Some studies demonstrated that variations in pulse characteristics could produce different responses,depending on the type of cell or tissue under study and on its functional status. For example,the calcium content of isolated chodrocytes could be increased or decreased by altering the pulse design and DNA synthesis could be changed with a high level of specificity. Thus,the choise of pulse types is very important. We chose bipolar signal and unipolar signal in order to test the effects in the clinical repair of non-unions. If the pair of coils is mounted anteriorly and posteriorly on the surface of the cast and is plugged into our designed driver,magnetic field depends in part on the distance between two coils. As current flows in the coils, a pulsing magnetic field is established between the pair,penetrating the cast and saft tissues. The field is magnetic flux lines(B field),which are at right angles to the bone include a voltage drop(E field at a right cycle to the B field) along the long axis(fig3).

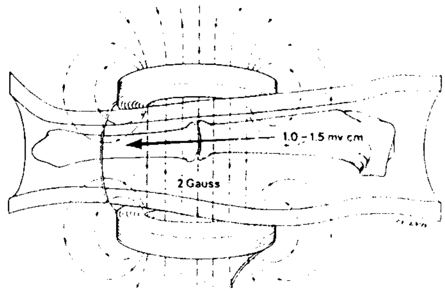


Fig 3. B-field and E-field path in the bone

To determine induced waveform parameters we must know the signal in the bone. Genernally the value of E field in the deformed bone is 1-100mV/cm and pulse duration includes various duty cycles. The conditions of designs of coils as well as driver circuits should have homogeneous voltage drop at 1.5 to 2 centimeter at intervals along the line of bone fracture when choosing driving voltage. Induced voltage field pattern on actual model measures to put electrodes on the surface of bone sites.

3.Experimental design

The present investigation was designed to compare the relative effects of pulsed unipolar currents with the effects of an identical pulsed bipolar currents(fig4).

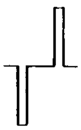
	pulse width(s)	Amplitude(v)	frequency(Hz)
	0.2 - 0.5	8 - 9 V	0.7 - 60
	0.2 - 0.5	8 - 9 V	0.7 - 60

Fig 4. Input waveforms

4.Experimental set up and apparatus

1)Treatment coil

Experimental animals(rabbits or dogs) in individual restraining boxes were placed between a pair of round,vertically placed air-cored coils ,6cm in diameter. The boxes were positioned so that the animals forlimbs were approximately midway between the edges of the coil and the central axis. The axis of the radius,although genernally perpendicular to the magnetic field lines(B-field) may move randomly. The signal was transmitted to the active coil,includeing a time-varying magnetic field;this in turn induced a time-varying electrical field in the bone. The self-inductance(15mH) of each coil is designed to produce 1 to 100mV/cm of induced current in the bone for any prescribed distance between the coils which vary with the width of the plaster used. A pair of externally-placed oval air-cored coils is driven by a small portable driver. The shapes of coils in the study are shown in (fig5).

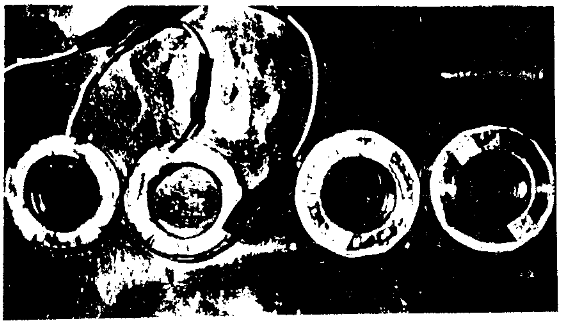


Fig 5. The shape of treatment coils

2)Drive circuit

The circuit driver(fig6) that was used in this study produced a unipolar and bipolar nine-volt peak to peak,0.7 to 60Hz,asymmetrical quarsirectangular wave signal. The amount of current produced by the power soure,as measured at the level of the animal's skin,ranged from 50mA to 5A RMS(root mean squire). The power souce was supplied by a nine-volt battery,which could be replaced with a fresh battery each day by the experimentors. The entire power unit measured twelve by six by four centimeters and weighted 250grams. Each battery was designed to be checked daily by means of builtin indicator lamps(LED).

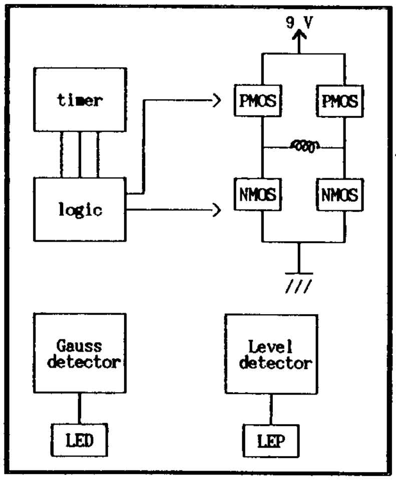


Fig 6. Block diagram for coil driver circuit

3)Measurement

Field characteristics were determined by introducing a Gauss meter into the mid-center axis of the pairs of air-cored coils. This search probe consisted of long bar,20 centimeter with an internal diameter of 0.8 centimeter. The detector leads were connected to a DVM and the induced B-field was read dirctly by the form of voltage calibrated(fig7). The oscilloscope recorded output from the load-cell

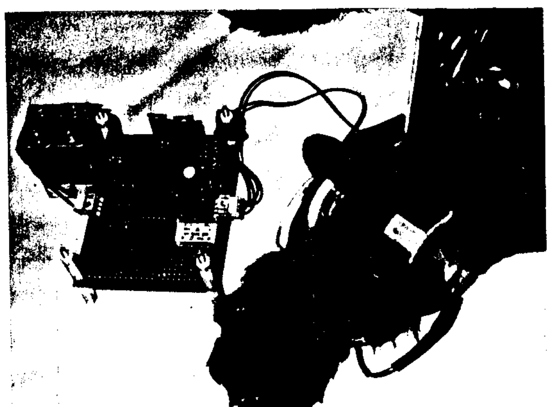


Fig 7. Measurement methods

5.Methods and materials

Each model was designed to produce a field strength of 100 to 400G at the midpoint between a pair of air-cored coils. The pulsed magnetic field is determined while the animal is confined to bed in a desk with the leg in a horizontal posistion. Treatment can be carried out at laberatory. The choice of a rate of 0.7Hz which we use three times is partly because of technical constraints,but also because it has shown that the transfer functions of bone as a piezo-electric transducer involves time constants comparable to those involved in walking frequency of 0.7Hz is optimal. The treatment of established non-union is very important to design to test the following conditions: 1)frequency 2)duty cycle 3)driving voltage 4)driving current 5)induction E-field 6)B-field Gauss 7)bipolar or unipolar signals. For that purpose,the rabbits were prepared and with the main transfer function we recorded in turn to satisfy above conditions,applying each conditions to the animals.

6.Results

The greatest differences between unipolar and bipolar signals were driving current and voltage. The reasons might consist of complex driver circuit(including FETs and several IC chips),but they could reduce the size of air-cored coils. Treatment with pulsing magnetic fields for both groups was the same driving voltage except swiches,but very differnt currents and Gauss valus. In the group with unipolar pulse signal currents produced smaller than in the group with bipolar pulse signal. The average of currents in the former group was 2Amp(50mA to 3Amp),compared with an average of current(3.5Amp)(range,3Amp to 5Amp)in the bipolar group. It is enough to induce desired Gauss values. Induced magnetic field and electric fields,pulsed at a very low frequency(0.7Hz) in the treatment of bone were compared with those at relative high frequencies(fig8).

G1. Bipolar signal

freq	B(G)	E(mV/cm)	I(A)	duty(%)
0.7	380	98	5	10%
10	360	97	4.5	10 %
0.7	380	98	4.7	20 %
30	350	97	4.3	20 %
0.7	350	95	4	50 %
60	300	81	3	50 %

G2. Unipolar signal

freq	B(G)	E(mV/cm)	I(A)	duty(%)
0.7	330	70	3.5	10 %
10	330	65	3.5	10 %
0.7	320	70	3.5	20 %
30	300	63	3	20 %
0.7	200	50	2.5	50 %
60	150	30	1.5	50 %

Fig 8. Measurement paramenters in the bone.
(L(mH):15mH,V:9V,I.D(cm):6cm(diameter))

7. Discussion

This treatment is simple and it appears to be safe. With some metal pins the effectiveness of the treatment may be questioned. The mechanism whereby a pulsed magnetic field might stimulate fracture healing remains obscure. Thus in order to form a suitable mechanism we must choose the driving voltage and current which induce magnetic field and electric field along the bone. The important reasons will be said that the time to union of the magnetically treated patients was much shoter than for the other methods. Several factors contribute to the high failure rate. Each system is jurged by the healing time altogether each parameters and we think that such system must have referance of apparatus. It seems,from the results of this preliminary study,that inductively magnetic field is as effective in treating non-union as are other forms of electrical treatment using direct current. Instead of sinusoidal signal the particular pulses in the study are quarsirectangular in design and generally are similar to those found in stressed,wet,living bone. Our results are encouraging and this form of treatment warrants further investigation. An extensive study is now being conducted.

8.References

(1) Bussett CAL,Mitchell SN,Repair of ununited tibial diaphyseal fractures with pulsing electromagnetic fields. Orthop Trans 1980:4:296-7.
(2) Bussett CAL,Mitchell SN,Gaston SR. Treatment of ununited tibial diaphyseal fractures. J Bone Joint Surg [Am] 1981:63-A:511-23.
(3) Bussett CAL,Mitchell SN,Norton L,Pilla AA.Repair of non-unions by pulsing electromagnetic fields.Acta Orthop Belg 1978:44:706-24.

(4) Bussett CAL,Pilla AA.Pawluk RJ.A non-operative salvage of surgically-resistant pseudarthroses and non-unions by pulsing electromagnetic fields:a preliminary report.Clin Orthop 1977:124:128-43.
(5)Brashear HR.Diagnosis and prevention of non-union.J Bone Joint Surg [Am] 1965:47-A:174-8.
(6) Brighton CT,Friedenberg ZB,Zemsky LM,Pollis PR.Direct-current stimulation of non-union and congenital pseudarthrosis:exploration of its clinical application.J Bone Joint Surg [Am] 1975:57-A:368-77.
(7) Brighton CT,Friedenberg ZB,Mitchell EI,Booth RE.Treatment of nonunion with constant Direct current.Clin Orthop 1977:124:106-23.
(8) Brighton CT, Black J,Friedenberg ZB,Esterhai JL,Day LJ,Connolly JF.A multicenter study of the Treatment of non-union with constant Direct current.J Bone Joint Surg [Am] 1981:63-A:2-13.
(9) Cochran,G.V.B.; Pawluk,R.J.; and Bassett, C.A.L.; Electromechanical Characteristics of Bone under physiologic Moisture Conditions.Clin Orthop 1968:58:249-270.
(10) Cruess,R.L.;Kan,K,;and Bassett,C.A.L.; The effects of Electromagnetic fields upon bone formation retes in experimental osteoporosis.Orthop Trans 1980:4:226-227.
(11) Dehaas,W.G.:Lazarovici.M.A and Morrison,D.M: The Effect of Low frequency Magnetic Fields on the Healing of the Osteotomized Rabbit Radius.Clin.Orthop,145:245-251,1979.