A STUDY OF THE EFFECT OF PULSED ELECTROMAGNETIC WAVES ON THE BLOOD FLOW OF A NORMAL LIMB

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THE mechanism of healing in a fractured long bone, despite its common occurrence, remains the subject of debate and investigation.1 The factors which initiate, guide and control the various processes of bone repair are still ill-understood. The recent use of electrical stimulation of bone, particularly in non-union and in pseudarthrosis of the tibia has gained popularity as a possible method of inducing osteogenesis. The first report of the use of electrical stimulation to enhance the healing of fractures was by Hartshone,2 but until fifteen years ago little was known of the effects of electricity on bone. Since then there has been an exponential rise in the number of publications3 and the literature on the subject is both bewildering and confused.4 It is still not clear what method of electrical stimulation is correct, what the current should be, where the anodes and cathodes should be placed, what pulsing of electro-magnetic fields is correct or indeed whether the technique has any significant effect on human bone at all. The association of piezoelectrical potentials and remodelling of bone according to Wolff's Law is altogether a different concept from its ability to induce osteogenesis in a non-union. The electrical potentials observed on stressing a bone do not depend on the viability of the tissue and the mechanism by which they reduce changes in bone is unclear. The effect on bone is generally held to be a piezoelectric effect,5,6,7 but others have postulated a pyro-electrical effect8 or an ion exchange mechanism.9

The mass of evidence, however uncontrolled and circumstantial, points to electricity as a possible signal which may redirect the response of a cell by changing its physical environment. The electrical signal may not be a direct stimulus but indirect, acting by some other physiological mechanism. The physiological mechanism may also be initiated by a number of other different signals. The effect of blood supply on fracture healing is accepted and it is possible that the physiological mechanism involves the blood supply. A fracture of the tibia in the dog produces a dramatic increase in total limb blood flow and specific receptors controlling flow changes are present in the soft tissues and periosteum surrounding the fractured bone.10 Increased vascularity was confirmed in the human fractured

Requests for Reprints should be sent to Mr R. A. B. Mollan, Department of Orthopaedic Surgery, The Clinical Research Unit, Musgrave Park Hospital, Stockman's Lane, Belfast BT9 7JB.
tibia by Rhinelander. In a study of pulsed electromagnetic stimulation in the human fractured tibia Jørgensen observed that with a current in an order of magnitude higher than that used to-day there was an increase in skin temperature at five minutes and maximal at fifteen minutes after application of the electric current. The finding was illustrated by thermography. He postulated that the effect was due to an electrochemical reaction causing vasodilation. However, it is possible that electricity, no matter how induced or at whatever current may, by a change in blood flow, change the environment of the cell in such a way as to induce or enhance osteogenesis. The change in flow could be an effect similar to sympathectomy, i.e. electrical stimulation might block nerve conduction or by a direct effect on local receptors it could cause a vasodilation. A literature search has failed to show any report of the effect of electromagnetic stimulation on the blood flow in a normal limb. Therefore a study investigating the effect of pulsed electromagnetic waves on the calf blood flow of normal subjects was undertaken.

**METHOD**

**Electromagnetic Induction**

An electronic device as constructed to deliver a train of pulses 200u sec. wide in bursts every 5m.sec. These bursts repeated at a frequency of 10-15 Hz. To obtain such a configuration three separate signal generators were used 5000 Hz, 200 Hz and 10-15 Hz to produce a composite signal. The signal was then amplified and fed into a set of coils wired in series. The resulting electro-magnetic waves between the coils were sufficient to produce an induced voltage 1.5 to 4.5 mV/cm in a search coil between the inducing coils.

**Measurement of Calf Blood Flow**

Experiments were carried out on eight healthy male volunteers aged 21-28 years lying lightly clad in a laboratory maintained at 23-24°C.

In the first series of four experiments, the coils were applied to the left thigh and right and left calf blood flow were measured by venous occlusion plethysmography using conventional metal water-filled plethysmographs.

In the second series of four experiments, the coils were incorporated in a specially constructed water-filled plethysmograph made of polycarbonate. Thus the electromagnetic field was applied to the calf at the level at which blood flow was being measured.

In all experiments, calf blood flow was recorded for a three minute control period. The coils were then switched on without the subject's knowledge and flows were recorded for a further three minute period. The coils remained switched on for thirty minutes before being switched off, again without the subject's knowledge. Three minute periods of blood flow were recorded when the coils had been on for ten, twenty, and twenty-seven minutes and for three minutes after switching them off.

**RESULTS**

**Coils applied to left thigh**

Before the coils were switched on, the mean left calf blood flow for the group of four subjects was 1.9 ml/100 ml/min (S.E.± 0.1). Mean flow while the coils were
switched on was 2.0 (±0.1), 2.2. (±0.1), 2.3 (±0.1) and 2.4 (±0.1) ml/min. During the three minute period immediately after the coils were switched off, mean left calf blood flow was 2.7 ml/100 ml/min (±0.1).

Similar changes were seen throughout this period in the control right calf. Blood flow rose from an initial value of 2.3 ml/100 ml/min (±0.1) to 2.4 (±0.1), 2.3 (±0.1), 2.5 (±0.1), 2.6 (±0.1) while the coils were on and was 2.8 ml/100 ml/min (±0.1) after the coils had been switched off.

There was no significant difference at the 5% level between right and left calf flows at corresponding times.

**Coils Applied to Left Calf**

The pattern was similar to that in the first series of experiments. Left calf blood flow was 3.0 ml/100 ml/min (±0.2) before the coils were switched on, 3.3 (±0.1), 3.0 (±0.1), 3.1 (±0.2), 3.2 (±0.2) while the coils were on and 3.4 (±0.2) after they had been switched off.

Corresponding values in the control right calf were 2.7 (±0.1), 2.9 (±0.1), 2.8 (±0.1), 2.7 (±0.1), 3.0 (±0.1) and 3.2 (±0.2).

Once again, there was no significant difference at the 5% level between right and left flows at corresponding times.

**DISCUSSION**

Electromagnetic stimulation of a normal limb failed to produce a significant increase in limb blood flow. This finding could mean that electromagnetic induction of the type used for the treatment of non-unions did not affect blood flow. It could also mean that the stimulation was not applied for a long enough time to affect blood flow (presumably by an indirect mechanism). The other possibility is that small changes in blood flow to bone did occur but were not detected by the method of blood flow measurement used. Venous occlusion plethysmography estimates total limb blood flow and therefore includes skin and muscle components as well as blood flow to bone. Since blood flow through normal bone is about 10% of the total flow, skin and muscle flow make the major contribution. Therefore, if the pulsed electromagnetic waves produced only small changes in bone blood flow and no change in skin and muscle flow, these might not have been detected by venous occlusion plethysmography. However, if the electromagnetic waves do affect blood flow either by a direct effect on the blood vessels themselves or indirectly via metabolic factors, it seems likely that blood flow to all tissues—skin muscle and bone—would be affected.

If we are to embark on expensive and time consuming regimes, and electrical stimulation can be either invasive in its own right or associated with other invasive procedures as part of the regime, or if we raise our patients hopes with prolonged period of immobilisation, then we must understand more fully what we are trying to do before attributing healing to a single process. Many electrical stimulation regimes involve reoperation, bone grafting, internal fixation and graduated exercise programmes, in these cases the effect of electrical stimulation per se is impossible to assess. We must enquire further into the mechanism of electrical stimulation to be sure that the phenomenon is a real one and a direct effect on osteogenesis. Only then can we weigh the benefit of the regime against the efficacy of such treatment.
SUMMARY

The blood flow in the normal lower limb was investigated after pulsed electromagnetic stimulation. No change in the blood flow was detected. It was concluded that electrical stimulation did not directly increase the blood flow to the limb, a mechanism thought to enhance osteogenesis.

REFERENCES

1. McKibbin B. The biology of fracture healing in long bones. *J Bone Joint Surg (Br)* 1978; 60B: 150-61.
2. Hartshorne E. On the causes and treatment of pseudoarthrosis and especially of that form of it sometimes called supernumerary joint. *Am J Med Sci* 1841; 1: 143-4.
3. Spadaro JA. Electrically stimulated bone growth in animals and man. *Clin Orthop Relat Res* 1977; 122: 325-32.
4. Brighton CT. Bioelectrical effects on bone and cartilage. *Clin Orthop Relat Res* 1977; 124: 1-4.
5. Bassett CAL, Becher RO. Generation of electrical potentials by bone in response to mechanical stress. *Science* 1962; 137: 1063-64.
6. Sharmos MJ, Lavine LS. Physical bases for bioelectric effects in mineralised tissues. *Clin Orthop Relat Res* 1964; 35: 177-88.
7. Yasuda I. Piezoelectricity of bone. *J Kyoto Med Soc* 1953; 4: 395-06.
8. Lang SB. Pyroelectric effect in bone and tendon. *Nature (London)* 1966; 212: 704-7.
9. John TL. A possible mechanism for the effect of electrical potentials on apatite formation in bone. *Clin Orthop Relat Res* 1968; 56: 261-73.
10. Wray JB. Acute changes in femoral arterial blood flow after closed tibial fracture in dogs. *J Bone Joint Surg (Am)* 1964; 46A: 1262-68.
11. Spadaro JA. Electrically stimulated bone growth in animals and man. *Clin Orthop Relat Res* 1977; 122; 325-32.
12. Jørgensen TE. The effect of electric current on the healing time of crural fractures. *Acta Orthop Scand* 1971; 43: 421-37.
13. Greenfield ADM. Methods for the investigation of peripheral blood flow. *Brit Med Bull* 1963; 19: 101-4.