THE TREATMENT OF FIBROUS NON-UNION OF FRACTURES BY PULSING ELECTROMAGNETIC STIMULATION

W. J. W. SHARRARD, M. L. SUTCLIFFE, M. J. ROBSON, A. G. MACEACHERN

From the Orthopaedic Department, The Royal Hallamshire Hospital, Sheffield

Fifty-three ununited fractures with a median time since injury of 28 months were treated by electrical stimulation using pulsing electromagnetic fields. Union was achieved in 38 cases (71.7 per cent) in a median time of six months. For ununited fractures of the tibia the success rate was higher at 86.7 per cent. Previous or active sepsis, the presence of plates or nails, the age of the patient or the time since the injury did not affect the results. Analysis of the failures suggests that inadequate immobilisation, a fracture gap of more than five millimetres or the presence of a screw in the fracture gap was responsible. In four patients no cause of failure could be determined.

The use of electricity to heal ununited fractures has been the subject of controversy since Hartshorne’s original description in 1841. In the last 10 years there has been an increasing interest in the subject (Spadaro 1977). 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 (Brighton et al. 1975, 1977, 1981; Bassett, Pillia and Pawluk 1977; Bassett and Mitchell 1980; de Haas, Watson and Morrison 1980; Paterson, Lewis and Cass 1980; Bassett, Mitchell and Gaston 1981). The purpose of this paper is to report a series of 53 unselected fractures with fibrous non-union in adults treated by pulsing electromagnetic stimulation and followed for at least one year.

Non-union has been defined in this series as failure of a bone to unite after one year with the added criterion that no alteration in radiological appearance has occurred for at least the preceding three months. These criteria were chosen because union had not been seen to take place in any fracture with this combination of clinical and radiological features with conservative management alone. No patient in this series had been operated on for at least six months before starting electromagnetic treatment nor was any operation made to the site of the non-union during the electromagnetic treatment. Thus the effects of electromagnetic treatment used with simple outpatient conservative management alone could be assessed.

METHOD

The system used was that described by Bassett et al. in 1977. An electric current of highly-specific shape, magnitude and repetition rate is generated in the bone by a pair of externally-placed oval air-cored electromagnets driven by a small portable generator (Fig. 1). This generator produces a five-millisecond burst of quasi-rectangular asymmetrical pulses repeated at 15 hertz. The driving voltage to the coils is set to produce 1 to 1.5 millivolts of induced current in the bone for any prescribed distance between the coils which varies with the width of the plaster used. The coils were placed at the appropriate distance apart and carefully aligned since inaccurate positioning distorts the magnetic field and modifies the induced electric current.

Immobilisation to the same extent as would normally be used after a bone graft was a prerequisite of treatment. For the tibia a groin-to-toe plaster with the knee flexed at 30 degrees was adequate. For the femur a hip spica was needed but, as the series progressed, additional fixation with non-magnetic pins incorporated in the plaster was found to be necessary in some difficult cases. For the humerus a shoulder spica was a minimal requirement.

The clinical presence of non-union was confirmed by movement at the fracture site, pain on stressing it and tenderness over the site. A good quality radiograph was taken with the limb out of plaster and its radiographic features noted so that subsequent radiographs could be accurately compared.

Fig. 1

Air-cored electromagnetic coils and signal generator in position for treatment of an ununited tibial fracture.

W. J. W. Sharrard, MD, ChM, FRCS, Consultant Orthopaedic Surgeon M. L. Sutcliffe, FRCS, Senior Orthopaedic Registrar M. J. Robson, FRCS, Senior Orthopaedic Registrar A. G. MacEachern, FRCS, Senior Orthopaedic Registrar. Princess Elizabeth Orthopaedic Hospital, Wonford Road, Exeter EX2 4UE, England.

Requests for reprints should be sent to Mr W. J. W. Sharrard


VOL. 64-B, No. 2, 1982

189
Case 37. Figure 2—Ununited fracture of the tibia three years after injury. Treatment was started two months later. Figure 3—Increased radiographic density in the fracture gap after two months of pulsed electromagnetic treatment. Figure 4—Bony trabeculae crossing the gap after six months. Electromagnetic treatment was discontinued two months later. Figure 5—Cortical continuity.

Case 35. Figure 6—Four years and eight months after grafting of a bony defect following three operations for removal of an osteoid osteoma. Treatment was started six weeks later. Figure 7—Increased radiographic density in the gap after four months of pulsed electromagnetic treatment. Figure 8—Bony trabeculae crossing the gap after six weeks. Treatment was discontinued one month later. Figure 9—Cortical continuity.
The position of the coils was fixed by a square radio-opaque plastic locator block. This was taped on to the outside of the plaster and its position checked radiographically. Once the block was correctly positioned over the site of the ununited fracture it was incorporated in the plaster. The square locator block fitted into a female fitting on one of the coils. The other coil was then placed on the opposite side of the plaster, parallel and at 180 degrees to the locator coil. All patients were instructed to use the equipment for 12 to 16 hours per day and not to bear weight until told otherwise. The treatment was applied to outpatients and the apparatus was therefore used at the patient's home, mainly during sleep.

After three months of treatment a clinical and radiological assessment out of plaster was made (Figs 2 to 9). Frequent clinical examinations out of plaster were avoided to prevent damage to early tenuous union. The earliest radiological signs of progress towards union were a loss of density in the sclerotic bone ends (sclerosis), a blurring of the bone edges and a slight increase in the radiographic density in the gap between the bone ends (Figs 3 and 7). At the second stage, there was evidence of bony trabeculæ crossing the gap (trabecular bridging) (Figs 4 and 8). The third stage was the establishment of cortical continuity (Figs 5 and 9) followed one year to 18 months later by remodelling of the bone with re-establishment of the medullary canal. No new external callus forms and union takes place between the bone ends.

When there was clear evidence of sclerosis, blurring of the bone edges and early trabecular bridging, a programme of graduated axial compression exercises in plaster was started for all of the lesions of the lower limb. For stable and transverse non-unions these exercises consisted of striking the heel of the plaster on a pair of bathroom scales until 10 to 15 kilograms was registered. This was repeated 50 times, three times a day. If no aching developed at the fracture site these exercises were increased after three weeks to 25 to 30 kilograms 50 times, three times a day. If aching occurred these exercises were discontinued for one week and then recommenced at a lower weight. Patients with oblique, spiral or comminuted non-union were started at five to seven kilograms 50 times, three times a day for three weeks, progressing to 15 kilograms, then to 20 to 25 kilograms, to partial weight-bearing and finally to full weight-bearing.

Electromagnetic treatment was discontinued when there was no clinical mobility at the site of the non-union, no pain on stressing it and not more than slight tenderness over it. Radiographs in two planes were required to show bony trabeculæ crossing at least half the width of the defect. In all cases showing these radiological signs there was spontaneous further progress of union to consolidation. In some cases with complicated non-union lines or in which it was difficult to judge union, tomography or screening for movement under image intensification was found to be most helpful. In those cases in which there was some bone loss or where the configuration of the fracture was such that there were potentially weak areas following initial union the limb was protected in a removable moulded polythene splint until the union was judged strong enough to allow unprotected weight-bearing.

MATERIAL

Fifty-three fibrous non-unions in 52 patients of whom 35 were male and 17 female were treated. Their mean age was 37 years ranging from 13 years to 79 years. The bones affected are shown in Table I. The tibia was the most commonly affected bone. There were 23 non-unions after compound fractures, 23 after simple fractures (20 of which had been operated on) and seven after elective orthopaedic procedures.

Every known treatment, surgical or conservative, for non-union has been encountered in one or other patient in this series. One hundred and fifty-two operations had been performed, the maximum on any one patient being 10. These operations included 45 bone grafts with or without internal or external fixation and 25 fixation procedures with or without compression. Cast-bracing had been used for some patients but plaster splintage was the commonest form of treatment, there being 1158 months of recorded treatment in plaster giving a mean of 22.5 months per patient.

Sepsis had occurred in 24 limbs and in four there were still one or more discharging sinuses at the start of treatment. Thirteen infections followed compound injuries and 11 followed operative intervention; of these 11, six followed open reduction or fixation, three followed a delayed operation on a fracture and two followed an elective surgical procedure. The median time from the injury to the start of treatment was 28.2 months with a range of 1 to 25 years.

<table>
<thead>
<tr>
<th>Bones affected</th>
<th>Number (n=53)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibia</td>
<td>30</td>
</tr>
<tr>
<td>Femur</td>
<td>7</td>
</tr>
<tr>
<td>Ulna</td>
<td>6</td>
</tr>
<tr>
<td>Radius</td>
<td>4</td>
</tr>
<tr>
<td>Humerus</td>
<td>1</td>
</tr>
<tr>
<td>Capitellum</td>
<td>1</td>
</tr>
<tr>
<td>Knee</td>
<td>3 failed arthrodesis</td>
</tr>
<tr>
<td>Ankle</td>
<td>2</td>
</tr>
</tbody>
</table>

Sixty per cent of patients showed all three clinical signs of non-union—mobility, pain on stressing and tenderness at the site of non-union. A synovial pseudarthrosis was suspected when the non-union was highly mobile and painless and two such cases were excluded from this series. Plain anteroposterior and lateral radiographs were taken but when difficulty was encountered, oblique films, tomographs or screening for movement were used.

Radiography showed the direction of the fracture line to be transverse in 23 cases, oblique in 24 cases and very oblique in six cases. The bone ends were hypertrophic in 25 cases, oligotrophic in 21 cases and atrophic in seven cases. The minimal gap between the bone ends on plain radiographs varied from nil to 10 millimetres. In 44 cases it was two millimetres or less. Twenty-three tibial non-unions had an intact or united fibula but in seven the fibula had an ununited fracture or part of it had been removed for bone grafting.

RESULTS

Union was achieved in 38 out of 53 cases (71.7 per cent). Early in the series, refracture occurred during rehabilitation in four patients because of inadequate protection given after removal of the plaster. One patient declined further treatment; two fractures re-united and remained united after a further short period of immobilisation and electromagnetic treatment. One patient required a combination of additional external fixation, grafting and electromagnetic treatment. Union failed to occur in 15 cases (28.3 per cent), 13 being definite failures and two doubtful at the time of assessment.

The proportion of union according to the bone affected is shown in Table II. The greatest success was achieved in the tibia (86.7 per cent). The median time taken to reach union in the 38 cases was six months with a range of 3 to 16 months. Age did not seem to affect the result nor did the time which had elapsed between the accident and the start of treatment.

The direction of the line of non-union, whether
Twenty-one out of 25 hypertrophic non-unions united in a median time of five months. 13 out of 21 oligotrophic non-unions united in a median time of seven months and four out of seven atrophic non-unions united in a median time of seven-and-a-half months. If a minimum gap of over two millimetres was visible between the bone ends on plain radiography the proportion of unions fell. There were no successes in four cases in which the minimal radiological gap was more than five millimetres.

Sepsis did not adversely affect the proportion of unions; 17 out of 24 septic cases united in a median time of five months. Neither did the severity of injury; 18 out of 23 major or compound injuries united in a median time of six-and-a-half months.

When part of the fibula had been removed or the fibula was itself ununited only one united below the median time, two united with some delay and four failed to unite.

No side effects or complications from electromagnetic treatment were encountered.

DISCUSSION

There is no universally accepted definition of non-union of a fracture. Some authors such as Brashear (1965) and Forsted et al. (1978) define non-union as a state existing when union of the fracture will not occur without surgical intervention. Nicoll (1964) defined non-union as a condition in which, in the opinion of the surgeon, the fragments would not unite with further conservative treatment. More recently Brighton et al. (1981) defined it as the condition existing in a fractured bone in which all demonstrable reparative processes had ceased and bone continuity had not been restored.

Though useful definitions, these are open to considerable individual and subjective interpretation. A more objective definition was described by Müller, Allgöwer and Willenegger (1965). They suggest that nine months after injury should be the starting point defining non-union. However, if one examines Nicoll’s (1964) figures relating to a total of 50 cases of fracture of the tibia which were not united at 40 weeks, 10 of these (20 per cent) went on to union between 40 and 42 weeks. For this reason, it was felt that a minimum period of 12 months after injury, with the stipulation that there should have been no radiological change towards union for at least three months before the start of treatment, would prove the most testing definition for a trial of treatment for non-union. It seems very unlikely that any of our cases would have been expected to go on to spontaneous union with continued conservative treatment alone.

The clinical content of any series is important. Some series have been predominantly concerned with one bone such as the tibia (de Haas et al. 1980); the tibia has a more favourable response than other bones. Some series include considerable numbers of delayed unions with as short a time as four months after injury (Paterson et al. 1980; Brighton et al. 1981). In this series the patients had well-established non-union and, except for the exclusion of synovial pseudarthroses and pathological fractures, all the cases were unselected.

The overall success rate of 71.7 per cent is lower than the figures published by others (Brighton et al. 1975; 1981; Bassett et al. 1977, 1978, 1981; de Haas et al. 1980; Paterson et al. 1980). In other series, some cases in which treatment was given less than 12 months after injury might have united irrespective of electrical treatment. If this fact, and the unselected nature of cases in this series is taken into account, the results are similar to those reported by others. The success rate of 86.7 per cent achieved in the tibia is almost identical to that
reported in other series. The success rate of 52.2 per cent in bones other than the tibia is notable. It is possible that difficulties of immobilisation may be responsible for some of the differences between the results in the tibia and in other bones. This hypothesis is supported by the success and failure rate in tibial fractures in relation to the stability imparted by an intact or united fibula.

There were 15 failures in the series; factors thought to be of importance in non-union are listed in Table III. The most common cause of failure was inadequate immobilisation, either on its own (Cases 1, 11, 39 and 51) or in combination with other factors (Cases 4, 28 and 31). A gap between the bone ends in excess of five millimetres, due in two cases to plating in distraction, was present in four cases in the series and all four failed to unite. Similarly, a screw was in or very near the fracture non-union site in three cases in the series and all failed to unite. Other cases of non-union were a case of unsuspected synovial pseudarthrosis and inadequate bone stock in a failed knee arthrodesis after removal of an infected prosthesis. Despite the discovery of these aetiological factors, the cause of non-union could not be determined in four cases, although in one of these there was a considerable language barrier which may have been responsible as it was never clear whether the patient was co-operating fully or using the apparatus correctly.

CONCLUSIONS

The results obtained in this series indicate that electromagnetic stimulation applied in conjunction with adequate immobilisation promotes union in a high proportion of extremely refractory cases of ununited fractures or surgical insults. If the factors that have been found to be responsible for some of the failures are corrected or eliminated in future, a success rate of more than 85 per cent may be possible in the treatment of non-union by electromagnetic stimulation.

The authors wish to express their gratitude to Professor C. A. L. Bassett of the Orthopaedic Research Laboratories of Columbia University, New York for his support and encouragement and to Mr E. Wallner and Mr J. Fry of Electro-Biology International (UK) Ltd for valuable technical assistance and support.

REFERENCES


---

**Table III. Causes of failure**

<table>
<thead>
<tr>
<th>Case</th>
<th>Inadequate immobilisation</th>
<th>Screw in gap</th>
<th>Minimum gap &gt;5 mm</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Cause unknown</td>
</tr>
<tr>
<td>19</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Cause unknown. Possible language difficulties</td>
</tr>
<tr>
<td>28</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Unsuspected synovial pseudarthrosis</td>
</tr>
<tr>
<td>31</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Failed knee arthrodesis; loss of bone stock</td>
</tr>
<tr>
<td>44</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Ulna plated in distraction</td>
</tr>
<tr>
<td>45</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Cause unknown</td>
</tr>
<tr>
<td>49</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Cause unknown</td>
</tr>
<tr>
<td>50</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>