Effect of Pulsed Electromagnetic Field on Healing of Mandibular Fracture: A Preliminary Clinical Study

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Purpose: The aim of the present study was to evaluate the effect of a pulsed electromagnetic field on the healing of mandibular fractures. Pulsed electromagnetic fields have been shown to accelerate healing of fractures of the long bones.

Patients and Methods: A total of 12 patients with mandibular fractures were selected for the present study. Each patient was treated by closed reduction using maxillomandibular fixation (MMF) and was assigned into 1 of 2 equal groups. The fracture sites of group A only were exposed to pulsed electromagnetic fields (PEMF) 2 hours daily for 12 days, after 2 weeks postoperatively the MMF was removed. For group B (control group), the MMF was removed at 4 weeks postoperatively. The effectiveness of the 2 treatment modalities was evaluated clinically and radiographically using computerized densitometry. The data were statistically analyzed.

Results: After releasing the MMF, a bimanual mobility test of the fractured segments showed stability of the segments in all cases. An insignificant difference was found between the mean bone density values of the 2 groups at all study intervals. In contrast, the percentage of changes in bone density of the 2 groups revealed that group A had insignificant decreases at the 15th postoperative day and a significant increase 30 days postoperatively compared with group B.

Conclusions: From the present limited series of patients, PEMF stimulation might have a beneficial effect on the healing of mandibular fractures treated with closed reduction. However, additional research, using randomized controlled trials, should be conducted to ascertain its effectiveness compared with other treatment modalities.

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Mandible fractures are the second most frequent of the facial bone fractures.1,2 The treatment of mandibular fractures has evolved for thousands of years and will likely continue to change. The main objectives have been to restore the normal pain-free range of mandibular motion and the preinjury occlusion and contour of the mandible.3 The basic treatment principles of mandibular fractures include reduction, fixation, immobilization, and supportive therapies.3,4 These principles have been achieved using 1 of 2 methods. The first has involved wiring the teeth and jaws together for a period of 4 to 6 weeks to allow the broken jaw to heal (closed treatment). The second method has entailed surgical exposure of the fracture to allow the reduction and stabilization of the broken bone (open treatment).3,4

Closed treatment of mandibular fractures offers valuable advantages, including obviating hospitalization, surgical morbidity, and the relatively high cost.3,7 However, the need for a relatively long period of immobilization with the subsequent delay of rehabilitation has been its main disadvantage. Therefore, a reduction of the immobilization period by accelerating healing of the broken bone has been the topic of
numerous studies.8-12 A number of simple, noninvasive approaches have been used to enhance bone healing, including low-intensity pulsed ultrasound8-10 and PEMF, with varying success.

The beneficial effect of PEMF stimulation on bone healing has been reported. In 1976, Bassett et al13 demonstrated augmentation of bone repair by inductively coupled electromagnetic fields. In 1992, Greenough14 reported that PEMF might affect tissue healing through a primary effect on vascular growth. This potential mechanism for stimulation of the healing process was supported by Roland et al.15 Moreover, Smith et al16 showed that local application of PEMF waveforms elicited significant arteriolar vasodilation in the rat muscle.

A number of reports have shown the clinical application of PEMF in stimulating osteogenesis in patients with fracture nonunion,1718 treating delayed healing of foot and ankle arthrodesis,19 increasing spine fusion,2022 and treating femoral head osteonecrosis.23 PEMF stimulation in limb-lengthening procedures enhanced callus formation and maturation at the distraction site, allowing earlier removal of the external fixation device.24 However, its mechanism of osteogenesis enhancement has not been clear.25 The use of PEMF to stimulate osteogenesis in patients with mandibular fracture has not yet been reported. Therefore, the aim of the present study was to investigate the effectiveness of PEMFs in enhancing the healing of mandibular fractures treated by closed reduction and a short period of maxillomandibular fixation (MMF).

The assessment of bone healing of mandibular fracture presents a problem for maxillofacial surgeons because of the few methods available. Computer-assisted densitometric image analysis (CADIA) has been used to quantify the variations in bone mineralization occurring in many pathologic conditions (eg, osteoporosis, osteomalacia, hyperparathyroidism).26 This objective method offers excellent measurement reproduction and a high level of correlation between the values obtained and the loss or gain in bone mineral, as determined by atomic absorption spectroscopy after successive periods of bone demineralization.27

**Patients and Methods**

**STUDY DESIGN**

The present study was a prospective study of 12 patients with mandibular fracture selected from those attending the outpatient clinic of the oral and maxillofacial surgery department (Cairo University Faculty of Oral and Dental Medicine). The selection was determined using the following criteria:

1. Mandibular fracture at a tooth-bearing area (Fig 1)
2. Sufficient occluding teeth present on either side of the fracture to allow MMF using an arch bar or eyelet wiring
3. No infection at the fracture site
4. No systemic problems that could affect normal bone healing
5. Patients who chose closed reduction after a discussion of the options regarding closed or open reduction

On initial presentation to the department, the patients were clinically and radiographically evaluated. The demographic data of the selected patients, etiology of the fracture, and the fracture location are listed in Table 1.

**TREATMENT PHASE**

Each patient received 75 mg diclofenac sodium (Voltaren) intramuscularly immediately preoperatively. After placing the patient under local anesthesia, the mandible fractures were manually reduced, and the patients were placed into MMF using arch bars and 24-gauge circumdental wires (Fig 2) or eyelet wiring (according to the condition of the teeth and patient cooperation). The teeth present in the fracture line were not removed, unless they were mobile or interfering with reduction of the fracture.

**PATIENT GROUPS**

The patients were given the option of conventional treatment or PEMF and were thus assigned to 1 of 2 equal groups: group A (patients A1 through A6), the fracture sites were exposed to PEMF for 2 hours daily for 12 days, after 2 weeks postoperatively the MMF was removed, and group B (patients B1 through B6),...
the fracture sites acted as the controls, with the MMF removed 4 weeks postoperatively.

POSTOPERATIVE CARE

All patients received 1,500 mg sulbactam (Unicatm) intramuscularly every 12 hours for 4 days, pain medication, and chlorhexidine mouth rinse.

The fracture sites in group A only were exposed to PEMF for 2 hours daily for 12 days using EM-probe Solo device (pulse duration 200 nanoseconds, rise time 8 nanoseconds; electromagnetic segment at 50 MHz and down to kilohertz range) (Fig 3). The pulse was carrier modulated at 72 Hz. All PEMF sessions were performed in the oral and maxillofacial department (Cairo University Faculty of Oral and Dental Medicine, Cairo, Egypt) by one of us (A.A.). PEMF was applied at the fracture site as illustrated in Figure 4.

MMF was maintained for 2 weeks in group A and for 4 weeks in group B, except for patient B3, who was 13 years old. For that patient, the MMF was removed at 22 days postoperatively. The patients maintained a liquid and pureed diet during the MMF period. They were instructed to continue a soft diet for 3 weeks after MMF removal.

<table>
<thead>
<tr>
<th>Pt. No.</th>
<th>Age (yr)</th>
<th>Gender</th>
<th>Fracture Location</th>
<th>Fracture Etiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>23</td>
<td>Female</td>
<td>Left parasymphysial/right ramus</td>
<td>Fall</td>
</tr>
<tr>
<td>A2</td>
<td>19</td>
<td>Male</td>
<td>Right body</td>
<td>Interpersonal violence</td>
</tr>
<tr>
<td>A3</td>
<td>22</td>
<td>Male</td>
<td>Left body</td>
<td>Interpersonal violence</td>
</tr>
<tr>
<td>A4</td>
<td>19</td>
<td>Male</td>
<td>Left body</td>
<td>Vehicular accident</td>
</tr>
<tr>
<td>A5</td>
<td>36</td>
<td>Male</td>
<td>Left body</td>
<td>Vehicular accident</td>
</tr>
<tr>
<td>A6</td>
<td>23</td>
<td>Male</td>
<td>Left body</td>
<td>Vehicular accident</td>
</tr>
<tr>
<td>B1</td>
<td>18</td>
<td>Male</td>
<td>Left body/right angle</td>
<td>Vehicular accident</td>
</tr>
<tr>
<td>B2</td>
<td>13</td>
<td>Female</td>
<td>Right parasymphysial/left angle</td>
<td>Vehicular accident</td>
</tr>
<tr>
<td>B3</td>
<td>59</td>
<td>Male</td>
<td>Symphysial</td>
<td>Vehicular accident</td>
</tr>
<tr>
<td>B4</td>
<td>27</td>
<td>Male</td>
<td>Left parasymphysial</td>
<td>Interpersonal violence</td>
</tr>
<tr>
<td>B5</td>
<td>43</td>
<td>Female</td>
<td>Left body</td>
<td>Interpersonal violence</td>
</tr>
<tr>
<td>B6</td>
<td>35</td>
<td>Male</td>
<td>Left body</td>
<td>Vehicular accident</td>
</tr>
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All postoperative radiographs were taken using a direct digital panoramic machine (OT100 Instrumentarium Imaging, GE, Finland 2003) using the following exposure parameters: 85 kVp, 16 mA, and exposure of panoramic program set at 17.6 seconds. The same exposure parameters (which were electronically controlled according to preprogrammed procedures) were kept constant for the baseline and follow-up radiographs.

The digital images were manipulated using the ImageJ software (ImageJ is a public domain Java image processing program inspired by the National Institutes of Health). ImageJ can be used to measure the area mean and pixel value density; gray scale calibration is also available. On each image, an analysis of the changes in the mean gray value was performed using the line measurement facility of the software used. The unit of measurement for bone density is pixels (mean gray value). Successive lines were drawn along the whole length of each of the investigated fracture lines. The densitometry values were obtained for each line expressed in gray levels from 0 to 255. Each of these values corresponded to the average density of the fracture area (Fig 5).

An analysis was performed by the same radiologist twice at 2 different sessions, with a 1-week interval in between in an attempt to eliminate intraobserver error. The data of the 2 trials were pooled, and the mean was included in additional statistical analysis. All collected data were then tabulated and statistically analyzed. The data are presented as the mean ± standard deviation. The data were explored for normality using the Kolmogorov-Smirnov test. Student’s t test was used to compare the differences between the 2 groups. The paired t test was used to study the changes by time within each group. The significance level was set at $P \leq .05$. Statistical analysis was performed using the Statistical Package for Social Sciences, version 16.0, for Windows (SPSS, Chicago, IL).

Results

All patients passed the 1-month follow-up period for inclusion in the present study. Of the 12 patients, 9 were males (75%) and 3 were females (25%). Their age range was 13 to 59 years (mean 28). The etiology of fractures in the present study was a motor vehicle accident in 7 (58.3%), interpersonal violence in 4 (33.3%), and an accidental fall in 1 patient (8.3%).

All patients had developed mild edema immediately postoperatively. The edema had started to resolve by the third postoperative day and had completely resolved by the end of the first postoperative week. The intraoral and/or extraoral wounds had healed by the end of the first postoperative week. Infection related
to the fracture line was observed in 2 patients at the second postoperative week. The infection was successfully treated with sulbactam (Unicatm) 1,500 mg intramuscularly every 12 hours for 4 days. In group A, PEMF was well tolerated by all patients. The pain intensity had decreased from severe to mild by the end of the first postoperative week. In contrast, the patients in group B had reached this grade by 2 weeks postoperatively. After releasing the MMF (after 2 weeks for group A and 4 weeks for group B), the bimanual mobility test of the fractured segments showed stability of the segments in all patients. The preinjury occlusion had been maintained in all patients.

**FIGURE 5.** Panoramic radiograph of patient B1 demonstrating 1 of the lines drawn using ImageJ software. Similar lines were drawn parallel and 1-mm apart from this line until the whole fracture area had been covered.


**RADIOGRAPHIC FINDINGS**

The postoperative radiographs of all patients revealed good bony alignment of the bony segments (Fig 6). An insignificant difference was found between the mean bone density values of the 2 groups throughout the study period (Table 2 and Fig 7). However, the changes in bone density within the same period were dependent on the treatment modality used. This became obvious after the expression of the increase or decrease in the bone densities in percentages. At 15 days postoperatively, the mean density in the fracture sites had decreased by 2.3% on average in group A and by 6% on average in group B. At 30 days
postoperatively, the mean density in the fracture sites in group A had increased by 10.2% compared with the density found at 15 days postoperatively. In contrast, the density in group B had increased by 1.9%. A comparison of the percentage of change in bone density between the 2 groups showed that group A had had an insignificant decrease at the 15th postoperative day and a significant increase at 30 days postoperatively compared with the values found for group B (Table 3 and Fig 8).

Group A showed significant differences between the study intervals except between the immediate postoperative examination and the 30-day postopera-

<table>
<thead>
<tr>
<th>Period</th>
<th>Group A</th>
<th>Group B</th>
<th>P Value</th>
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<tbody>
<tr>
<td>Baseline</td>
<td>138.5 ± 32.4</td>
<td>124.5 ± 35.4</td>
<td>.492</td>
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<tr>
<td>15 d</td>
<td>135.4 ± 32.4</td>
<td>115.7 ± 34.5</td>
<td>.330</td>
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<tr>
<td>30 d</td>
<td>147.3 ± 28.5</td>
<td>118.5 ± 38.3</td>
<td>.171</td>
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Data presented as mean ± standard deviation.

tive examination (Table 4 and Fig 9). In contrast, insignificant differences were noted between the study intervals in group B (Table 5 and Fig 9).

Discussion

Numerous studies have focused on the outcome and morbidity associated with the treatment of mandibular fractures. However, some controversy remains regarding the optimal treatment modalities for these fractures. Closed reduction techniques have yielded a lower level of complications compared with open techniques; however, the need for a relatively long period of immobilization, with the subsequent delay of rehabilitation, has been their main drawback.29-31 Traditionally, the duration of MMF used for adult mandibular fractures has been 6 to 8 weeks.32 In the present study, all the patients in group B had clinical stability after removal of the MMF at 4 weeks postoperatively (100%). This finding is in general agreement with those of other studies.33,34 Juniper and Awty33 reported that 80% of mandibular fractures treated with open or closed reduction and MMF were clinically united by 4 weeks. Amaratunga34 found that 75% of mandibular fractures were clinically stable by 4 weeks, that almost all fractures in children had healed within 2 weeks, and that a significant number of fractures in older patients needed 8 weeks to heal. Al-Belasy35 found that the period required for the healing of mandibular fractures in the tooth-bearing area treated by MMF was 4.67±0.72 weeks.

Amaratunga34 suggested the application of a short 2-week period of immobilization, followed by splinting the lower jaw with an arch bar or acrylic splint, or a period of a soft diet as options available to the surgeon for the treatment of mandibular fracture. Al-Belasy35 compared the use of a 2-week period of MMF followed by an arch bar splint wired to the lower jaw for an additional 4 weeks with a 6-week period of MMF for the treatment of mandibular fractures in the tooth-bearing area and found the period required for fracture healing was 4.93±0.7 and 4.67±0.72 weeks, respectively. In contrast to the modification of the stabilizing methods of closed treatment, the objective of the present study was to enhance bone healing with PEMF stimulation. It was impressive that the mandibular fractures treated with simultaneous PEMF stimulation and MMF for 2 weeks (group A) were clinically stable within 2 weeks. This could be explained by the conclusions from other orthopedic studies36-39 that the use of PEMF accelerates bone regeneration, increases osteogenesis in vitro,40 and maturation of callus in vivo.41 However,

<table>
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<tr>
<th>Table 3. RESULTS OF STUDENT t TEST FOR COMPARISON BETWEEN PERCENTAGE OF CHANGES IN BONE DENSITY</th>
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<tr>
<td>Period</td>
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<tr>
<td>Baseline to 15 d</td>
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<tr>
<td>15 d to 30 d</td>
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<td>Baseline to 30 d</td>
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Data presented as mean ± standard deviation.
*Significant at P ≤ .05.


<table>
<thead>
<tr>
<th>Table 4. RESULTS OF PAIRED t TEST FOR CHANGES BY TIME WITHIN GROUP A</th>
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<tr>
<td>Period</td>
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<tr>
<td>Baseline to 15 d</td>
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<tr>
<td>15 d to 30 d</td>
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<tr>
<td>Baseline to 30 d</td>
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</tbody>
</table>

Data presented as mean ± standard deviation.
*Significant at P ≤ .05.

our findings contradict those from Markov\textsuperscript{42} that one should not expect that the magnetic field that is beneficial for superficial wounds would be as good for fracture healing.

In the present study, the reduction of pain intensity from severe to mild by the end of the first postoperative week was noted in all patients in group A. In contrast, the patients in group B reached this grade by 2 weeks postoperatively. This can be attributed to the analgesic and antinociceptive effects of PEMF. Numerous studies have reported on the effectiveness of PEMF in relieving pain with, however, contradictory results.\textsuperscript{43-46} Lap et al\textsuperscript{45} tested the value of PEMF therapy in the treatment of pain. They found that patients with chronic pain refractory to conventional conservative methods showed significant subjective pain improvement after application of PEMF for 20 minutes daily for 10 days.\textsuperscript{43} Other investigators have also reported similar experiences.\textsuperscript{44-46} However, Weintraub et al\textsuperscript{47} found PEMF ineffective in reducing diabetic neuropathic pain. These inconsistent results could have resulted from the use of fields of varying strengths and frequencies.

A wide variety of diagnostic methods have been used to assess the process of bone fracture healing. However, the necessity for noninvasive and repetitive methods has drawn the attention of many researchers toward the application of CADIA. Experimental studies found a significant correlation between CADIA and the quantitative histologic measurements of bone mineralization\textsuperscript{48-51} and proved the validity of CADIA for detecting changes in bone density and mineralization, with highly reproducible measurements.\textsuperscript{48-50} In the present study, the digital images were manipulated using ImageJ software, which has been used in published studies to measure the changes in the bone density of the mandible.\textsuperscript{52-54} CADIA of both groups showed a decrease in the mean bone densities at 15 days postoperatively, corresponding to the initial stage of healing.\textsuperscript{55} At 30 days postoperatively, an increase in these values was noted, corresponding to the second—the “soft” callus—stage of healing.\textsuperscript{55} These findings were in general agreement with those from Razukevičius et al,\textsuperscript{56} who reported that the greatest decrease in optical density was observed during the second week and that the mean optical densities in the fracture site started to increase, with the greatest increase in the optical densities in the fracture site registered at the sixth to eighth week after repositioning and fixation of the fracture fragments. In contrast, Villarreal et al,\textsuperscript{57} in an evaluation of mandibular fracture repair after either MMF or rigid internal fixation using CADIA demonstrated an unexpected increase in density at 15 days and attributed it to soft tissue edema and swelling. At 30 days, a significantly greater decrease in optical density was observed in the MMF group that was attributed to the formation of soft fracture callus.\textsuperscript{57}

| Table 5. RESULTS OF PAIRED t TEST FOR CHANGES BY TIME WITHIN GROUP B |
|-----------------------|--------------|-------------|
| Period                | Mean Difference | P Value  |
| Baseline to 15 d      | $-8.8 \pm 18.1$ | .287       |
| 15 d to 30 d          | $2.9 \pm 6.7$  | .355       |
| Baseline to 30 d      | $-5.9 \pm 11.6$ | .570       |

Data presented as mean ± standard deviation.

In the present study, the most striking differences in the healing process between the 2 treatment modalities were noted using quantitative radiodensitometry. The changes in the mean bone density after fracture fragment repositioning and fixation were analogous in both groups, as evident by the lack of a significant difference between mean bone densities in the 2 groups throughout the study period. However, the percentage of changes in bone density in group A showed an insignificantly lower decrease by the 15th postoperative day. This could be explained by the observation of Cruess et al58 that PEMF reduced bone loss (osteoclastis) in animals subjected to disuse osteoporosis. A significantly greater increase in the percentage of changes in bone density in group A was also noted at 30 days postoperatively. This might have been the result of enhanced osteogenesis, because PEMF has been shown to increase osteogenesis in vitro40 and the maturation of callus in vivo.41 Therefore, it seems that the percentage of changes in the bone densities within the same period were dependent on the treatment modality used. This finding confirms that of Razukevičius et al45 in their comparative analysis of the effectiveness of the mandibular angle fracture treatment methods. They showed that the percentage of changes in bone densities rather than their mean values was dependent on the fracture fragment fixation method.

According to the findings from our limited series of patients, PEMF stimulation might have beneficial effects on the healing of mandibular fractures treated with closed reduction. However, additional research, using randomized controlled trials, should be conducted to ascertain its effectiveness compared with other treatment modalities.

References