Do capacitively coupled electric fields accelerate tibial stress fracture healing?

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Do capacitively coupled electric fields accelerate tibial stress fracture healing? A randomized, controlled trial.

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Acknowledgments:

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Abstract (word count = 248)

Background: Tibial stress fractures increasingly affect athletes and military recruits, with few known effective management options. Electrical stimulation enhances regular fracture healing but the effect on stress fractures has not been definitively tested.

Hypothesis: Capacitively coupled electric field stimulation (CCEFS) will accelerate tibial stress fracture healing.

Study design: Double blind, randomized controlled clinical trial.

Methods: 20 men and 24 women with acute posteromedial tibial stress fracture were referred from local clinicians. Subjects were randomly assigned active or placebo CCEFS to be applied for 15 hours per day until healed, given supplemental calcium and instructed to rest from provocative training. Healing was confirmed when hopping to 10 cm for 30 seconds could be achieved without pain.

Results: No difference in time to healing was detected between treatment and placebo groups. Females in the treatment group healed more slowly than males (p = 0.05). Superior treatment compliance was associated with reduced time to healing (p = 0.003). Rest non-compliance was associated with increased time to healing (p = 0.05).

Conclusions: Whole group analysis did not detect an effect of CCEFS on tibial stress fracture healing, however, greater device use and less weight bearing loading enhanced the effectiveness of the active device. More severe stress fractures healed more quickly with CCEFS.
Clinical relevance: While the use of CCEFS for tibial stress fracture healing may not be efficacious for all, it may be indicated for the more severely injured or elite athlete/recruit whose incentive to return to activity may motivate superior compliance.

Key terms: STRESS FRACTURE; BONE STRESS INJURY; TREATMENT - NOVEL ENTITIES; ELECTRIC FIELD STIMULATION; FRACTURE STIMULATION
Introduction

Stress fractures are focal structural weaknesses in bone occurring with the repeated application of sub-fracture threshold forces (15). Stress fractures typically result from chronic skeletal overloading occurring over a period of time that is inadequate to allow appropriate bone adaptation. They are increasingly common injuries in athletic and military populations, and thought to affect more female army recruits than male(4, 21).

With some exceptions, fractures of this nature heal spontaneously if the injury site is relieved for a time from the aggravating loading. The period of time required for healing to occur with rest, however, can be quite prolonged. The most common site of stress fracture is the tibia(5). A comprehensive review of the literature reveals that an average of 12 ∨ 7 weeks rest has been recommended for the resolution of tibial stress fractures. Such a lengthy duration is highly problematic for athletes in critical training or competitive periods, for army recruits engaged in 14-week basic training courses, and for individuals simply attempting to maintain a level of fitness for health benefits.

Few treatments to enhance the rate of stress fracture healing have been empirically tested, and of those that have, results have been disappointing or equivocal. For example, the use of a pneumatic leg brace was reported to enhance the rate of healing in a small (n = 18) athlete study(35), but not in a larger (n = 31) controlled study of soldiers with tibial stress fractures(1).

Electric fields are known to activate the bone formation process in vitro(23). Furthermore, electric and electromagnetic field stimulation has been shown to facilitate the of healing of recalcitrant fractures in humans, in vivo(32-34). The rationale for the current study was based on the assumption that, as bone repairs via a similar mechanism regardless of the nature of the fracture, electric field stimulation should similarly promote healing of stress fractures.
fractures. Some preliminary evidence exists to support such an hypothesis(3), however, no controlled, randomized trial has previously been conducted to appropriately test the theory.

The current study objective, therefore, was to examine the effect of capacitively coupled electric field stimulation versus placebo treatment on rate of tibial stress fracture healing in men and women via a double blind, randomized, controlled trial. A capacitively coupled electric field (CCEF) device that operates with signal parameters known to stimulate osteoblasts and designed to optimize patient compliance was selected to deliver the intervention stimulation (OrthoPak® Bone Growth Stimulator Systems, EBI, formerly Biolectron, Inc., Hackensack, NJ; FDA approved for non-union fracture healing, see Figure 1).

Materials and Methods

The study was approved by the US Army Human Subjects Research Review Board, the Stanford University Panel on Human Subjects in Medical Research, the Griffith University Human Research Ethics Committee, and the Australian Defence Human Research Ethics Committee.

Sample size and power

Women and men between the ages of 18 and 50, recently diagnosed with one or more tibial stress fractures, were recruited from a subject pool of referrals from San Francisco Bay area (California, USA) and the Gold Coast region (Queensland, Australia) over a period of seven years. Apriori power calculations (based on a predicted effect size of 3 weeks, $s = 4$, $\alpha \leq 0.05$, and $\beta = 0.80$) indicated a total of 32 subjects (8 in each of 4 groups) would be required to detect between-group healing differences according to both device status and sex. We chose to recruit additional subjects to avoid potential group shortfalls consequent to blind random allocation,
aiming for a total of 40 subjects, 20 men and 20 women. Our figures were derived from the consideration that a healing time difference of three weeks would constitute a practically worthwhile effect, based on literature reports of an average time to tibial stress fracture healing of 12 weeks. Ultimately, power to detect differences between treatment and placebo groups based on our final subject numbers and times to healing was 95.7%, and power to detect differences between male and female responses was 100% for the 95% confidence interval. (See Figure 2, CONSORT diagram of subject flow.)

Subject selection

Eligibility for the study was based on the presence of one or more acute tibial stress fractures, for which no significant treatment, aside from rest, had been prescribed. Only posteromedial mid to distal third and proximal medial tibial stress fractures were investigated. Mid anterior tibial shaft stress fractures were excluded, being of dissimilar etiology to typical tibial stress fractures, and particularly prone to delayed- or non-union(14). Subjects were excluded from the study if they were pregnant, used a pacemaker, had a metabolic bone disease, or took medication known to influence bone healing.

Clinical diagnosis

Patients diagnosed with tibial stress fractures were referred to study investigators from local sports medicine clinicians. Study personnel then performed a comprehensive injury assessment to standardized evaluation criteria. The diagnosis of stress fracture was determined according to patient history (development of substantial, localized, exercise-related bone pain) and the presence of significant focal tenderness at either of the above described sites that was most pronounced during weight bearing loading. Intensity of signs and symptoms including: tenderness, night pain, pain with percussion, localized bone swelling, spongy texture overlying
the injury, and warmth at the site, were recorded on a scale of 1-3. A “clinical severity score” was calculated by the addition of all sign and symptom scores for a possible total of 21.

Diagnostic imaging

Although eligibility for study enrollment was based exclusively on clinical diagnosis, a comprehensive series of imaging examinations was ordered for each subject to obtain further information regarding injury severity. Plain x-rays have poor diagnostic sensitivity to stress fracture, detectable changes often lagging two to six weeks from onset of symptoms, but were obtained in order to standardize findings and rule out unforeseen pathology. Triple phase technetium bone scans are highly sensitive to bone stress reactions and are historically the most common imaging modality for stress fractures. Increasingly considered a more specific gold standard for stress fracture diagnosis, magnetic resonance images were taken at baseline and follow-up in order to more precisely observe location and degree of local swelling. Although not widely used, computed tomography has also been reported for stress fracture imaging, and thus was included in the radiological protocol for the purposes of comparison.

Severity of injury was graded on a scale of 0-4 for each method of imaging. A “radiological severity score” was calculated by the addition of imaging scores for each modality for a possible total out of 16. The total radiological severity score was stratified into four injury grades (grade 1 = 1-3, grade 2 = 4-6, grade 3 = 7-9 and grade 4 = >10) to approximate the stress fracture grading systems recently reported in the literature(2, 18-20, 36). The low-end range of the stratification was emphasized to account for the low sensitivity of plain films and CT, and the consequent likely small contribution of those scores to the overall radiological severity score.
All images were blinded and graded independently by musculoskeletal radiologists on separate occasions in order to evaluate inter-reader reliability. A complete description of the radiological analysis will be reported elsewhere.

Subject characteristics

A comprehensive record of relevant physical and behavioral characteristics was collected (age, height, weight, medical history, training patterns, orthopaedic abnormality, menstrual status, etc). Each subject completed a National Cancer Institute Health Habits Food Frequency Questionnaire (Block Dietary Systems, San Francisco, CA) to determine average daily calcium consumption in milligrams. Subjects were provided with calcium supplements (TUMS 500 Chewable, 500 mg calcium carbonate, SmithKline Beecham) and instructed to consume one supplement per day to ensure adequate calcium availability during the course of the intervention.

All subjects were examined by dual energy x-ray absorptiometry (XR-36 Quickscan densitometer, software version 2.5.3a, Norland Medical Systems, Inc., USA) to determine bone mineral density at the whole body, proximal femur, lumbar spine and forearm. A bone mass score was derived for each subject by calculating the average z score from all regions. Broadband ultrasound attenuation (BUA) of the non-dominant calcaneus was employed to record an additional index of bone quality (QUS-2 Ultrasound Densitometer, Quidel Corporation, CA, USA).

Treatment

Active and inactive (placebo) electric field stimulators (OrthoPak® Bone Growth Stimulator Systems, EBI, Hackensack, NJ), were provided coded and blinded to investigators by the manufacturers. The active device was a small, portable, capacitively coupled electric field
(CCEF) stimulator that applied a sinusoidal wave of 3 - 6 V at 60 kHz and 5 - 10 mA via two adhesive, water-based gel electrodes (Figure 1).

Once diagnosed, and baseline data collection was complete, each subject was immediately assigned a device with replacement 9 Volt batteries and electrodes, and the intervention initiated. The CCEF device manufacturer recommends that patients use the device constantly, unless engaged in water activities. Our subjects were instructed to use the device for 15 – 20 hours per day to maximise usage but minimize variability between subjects that was likely to occur as a consequence of a somewhat burdensome protocol. We instructed subjects to replace the battery every morning, and to keep the device alarm switched on. The alarm would sound if electrode contact was lost from the skin or battery power was low, an event signalling that the electric field had been interrupted. Electrode contact could be recovered by moistening the electrodes or replacing them. A daily treatment record log was provided for subjects to record actual hours of use and any side effects or exercise activity they undertook. Devices were issued according to sequential serial number, as device status had been randomized in this order. Active and inactive devices looked and ostensibly functioned in the same manner, and all subjects were treated identically.

All subjects received standard stress fracture rehabilitation advice in order to avoid treatment withholding from the placebo group. Regular rehabilitation primarily consisted of rest from any painful activity. In-saddle stationary cycling and pool running were acceptable training alternatives to repetitive weight bearing training. Crutches were available for subjects unable to perform activities of daily living without pain, but this was never the case. Subjects were issued with acetaminophen to be used as needed (Tylenol Extra Strength Gelcaps, 500 mg, McNeil Consumer Products, Fort Washington, PA, USA), and asked to avoid non-steroidal anti-
inflammatories (NSAIDS). No subject reported use of any form of pain medication during the course of the study.

**Subject monitoring**

Participants were contacted by phone or email every second day for a progress report and asked to re-rate any existing signs and symptoms from 1 – 3. Running was not attempted until subjects were pain free with walking, and hopping was not attempted until subjects were pain free with running (50 meters).

When a complete absence of pain during hopping on the affected limb for 30 seconds to a height of 10 centimetres off the ground was reported and confirmed by investigator examination, the subject was considered healed and the intervention ceased. Participants immediately received a follow-up MRI examination and returned their device and completed treatment log to investigators. Device use was tested using the manufacturer-provided Physician Test Meter which detected days of use in 24 hour periods. A functional measure of healing was deliberately chosen as the outcome measure, rather than appearance on follow-up imaging, in order to standardize the dependent variable to a practical benchmark and reflect usual practice for stress fracture management in the clinical setting. No standardized system of classification to confirm stress fracture healing on MRI was available at the study inception.

**Statistical analysis**

Device effect was evaluated via two-way ANOVA to determine if differences existed in time to healing between active and placebo treated subjects, and between men and women. As time to healing from start of treatment was positively skewed, we also performed a natural log (LN) transformation of the data and re-ran the ANOVA with LN time to heal from start of treatment as the dependent variable. In order to account for variation between subjects in
duration of injury before study enrollment, the analysis was run for both the time between date of injury and healing, and the time between initiation of intervention and healing. A further analysis was run to examine actual treatment time (time the device was worn) according to the Physician Test Meter. The latter varied from number of days to healing as subjects were instructed to use the device for only 15 hours per day.

To determine if severity of injury affected time to healing, a number of severity indices were also compared with outcome measures. Two-way ANOVA was used to compare time to healing using device status and clinical severity score as factors. Time to healing was also compared via two-way ANOVA using device status and radiological severity score as factors. Finally, time to healing according to tibial stress fracture injury grade (1-4) was compared via one-way ANOVA for the whole group and using a split file analysis for device status.

The effect of subject compliance with investigator instructions on treatment time was similarly examined via two-way ANOVA. One model examined actual hours of device use (from the Physician Test Meter) per number of real treatment days, i.e. treatment compliance, versus device status. Device use compliance was examined more closely by way of a t-test comparison of subjects who complied >70% with those who complied <70% using Physician Test Monitor hours to healing as the dependent variable. Further, a split file (according to device status) correlation analysis of days to healing from start of treatment versus device use compliance was performed. A second compliance model used a rating assigned to level of weight bearing activity during the intervention (derived from number and intensity of exercise bouts recorded in the subject log), that is, rest compliance, versus device status.

Correlation analyses were performed to observe the nature of specific relationships between time to healing and variables such as injury severity or delay to treatment start.
Results

A total of 50 tibial stress fracture treatments were initiated, of which 44 (20 male and 24 female) were completed. Twenty-three of the randomly allocated devices were active (9 to men, 14 to women), and 21 were placebo (11 to men, 10 to women). Subjects excluded from the final analyses included four misdiagnoses (one anterior tibial stress fracture, one hemangioma, two cases of complex regional pain syndrome Type I), two subjects released for failure to initiate the protocol, and one extreme outlier (see Figure 2).

All statistical analyses satisfied Levene’s test for homogeneity of variance for between group comparisons.

Subject characteristics are summarized in Table 1. Subjects were primarily involved in running and running-related activities (Table 2). Treatment versus placebo group comparisons revealed no subject characteristic differences with the exception of percent fat (active > placebo, p = 0.02) and percent lean mass (active < placebo, p = 0.03). Within sex, there were no differences between treatment and placebo groups with the same body composition exceptions. Women allocated an active device had significantly greater percent body fat (p = 0.02) and less lean mass (p = 0.03) than women issued a placebo device. Between sex group comparisons revealed predictable differences in height, weight, BMI, percent fat, percent lean mass and BUA, men being significantly taller and heavier with lower percent fat than women. Men consumed more calcium than women (1391.7 ± 689.1 vs 958.1 ± 359.9 mg, p = 0.02).

A summary of injury severity ratings and compliance scores is presented in Table 3. There were no differences in severity of injury between treatment and placebo groups, whether assessed clinically or radiologically. There were no detectable differences in treatment
compliance (number of hours per day of device use) between treatment and placebo groups, nor in degree of compliance with the instruction to rest from weight bearing activities during treatment. Similarly, no between-sex differences existed in any compliance or injury severity variable.

A summary of healing data is present in Table 4. There was no main effect of device status on time to healing from the start of treatment (treatment group - 29 days; placebo group - 25.9 days), however, overall women healed more slowly (31 days) than men (23 days) (p = 0.05). Analysis of the log transformed data revealed an interaction effect, such that the sex difference was only evident in the treatment group (Figure 3).

In the analyses of (i) treatment compliance (actual hours of device use per number of real treatment days), and (ii) rest compliance (amount of weight bearing activity during treatment) two main effects were revealed. Increased hours of device use per day was associated with greater reduction in time to healing in the treatment group than the placebo group (F = 57.533, p = 0.003). The split file correlation analysis similarly indicated a significant inverse relationship between time to healing and device use compliance for subjects allocated an active device (r = -3.55, p = 0.05), but no relationship for placebo allocated subjects (r = -.009, p = 0.972). Subjects who complied more than 70% (used the OrthoPak® for >12.25 hours/day) healed significantly faster than those who complied less than 70% (t = 2.739, p = 0.009, 95% CI 2.07, 13.797).

Greater engagement in weight bearing activities during treatment (rest non-compliance) increased the time to healing from the start of treatment for subjects using the active device in comparison with placebo users (F = 2.583, p = 0.05).

Although no main effects of clinical or radiological injury severity on time to healing, could be detected, a direct comparison of time to healing according to radiological injury grade
(1-4, described above) revealed significant between-group differences (F=4.79; p = 0.007).

When a split file analysis was run according to device status, time to healing differed between
subjects of different injury grades only if they were allocated a placebo device (F = 11.08; p =
0.001). That is, there were no differences between healing times of subjects with bone scan
severity grades of >2 versus ≤2 in the treatment group (23.5±16.3 vs 31.2±22.0 days,
respectively). However, there was a significant difference in healing time for the same
comparison of subjects allocated a placebo device (48.0 ± 36.8 vs 24.4 ± 8.7 days, p=0.01).

These figures indicate that grades 3 and 4 tibial stress fractures treated with an active device
healed 24.5 days faster than those allocated a placebo device. It is important to note that these
analyses are not sufficiently powered to make definitive conclusions owing to the small number
of subjects classified ≥2 in bone scan severity grade.

Correlation analyses revealed no significant relationships between time to healing and
variables such as injury severity or delay to treatment start. One exception was a split file
analysis for device status that reconfirmed a significant positive relationship between
radiological injury severity and time to healing from date of injury for subjects issued placebo
devices (Pearson’s r = 0.456, p =0.03). Appearance of follow-up MRI did not consistently
reflect clinical healing. The use of CCEFS bore no relationship to the appearance of post-
treatment MRI.

Discussion

Our goal was to examine the effect of capacitively coupled electric field stimulation on
rate of stress fracture healing with a level of study design rigor not previously reported. We
standardized stress fracture site and included both male and female subjects in a double blind, randomized, controlled trial.

Primary between-group comparisons detected no differences in rate of healing between treatment and placebo groups, but indicated that men healed an average of eight days faster than women from the initiation of treatment. The sex difference was small (2.4 days) in the placebo group, but significant in the treatment group wherein men healed an average of 13.2 days faster than the women, suggesting a sex-CCEF interaction effect existed. The observation that women but not men in the treatment group had greater percent body fat and less lean mass than the placebo group coincides with the sex-specific treatment effect. It is unclear how body composition might modify the effect of CCEF stimulation on stress fracture healing, as factors influencing and influenced by fat and lean mass were not measured. The observation of the significantly greater daily calcium consumption (433.6 mg) of male subjects versus female may be of relevance to the sex-specific treatment response.

Close scrutiny of the data suggests that an effect of electric field stimulation on stress fracture healing did exist. For example, increased hours of device use per day reduced time to healing in the treatment group but not the placebo group. The fact that the more severe tibial stress fractures treated with an active device healed substantially faster (24.5 days) than similar grade fractures treated with placebo, is additionally suggestive of a treatment effect. In order to prospectively test the hypothesis that tibial stress fracture injury grade influences the efficacy of CCEFS, future investigations must recruit adequate numbers of each stress fracture grade (1-4) in order to maximize statistical power for cross grade comparisons.

Electrical stimulation has been used sporadically by clinicians for over a century (28) (26). More recently electric and electromagnetic fields have been shown to effect responses
from bone cells in culture (7, 8, 16, 23, 31). Clinical effects such as the stimulation of bone
graft, spine fusion, osteotomy and non-union healing (9, 10, 12, 22, 27, 33), and the prevention of
disuse osteopenia (6, 30), have also been reported.

To date, only one study has investigated the effects of electric field stimulation on stress
fractures (3). Of twenty-five stress fractures treated with CCEFS (3.0 - 6.3 V, 60 kHz) for an
average time of 7.4 weeks (navicular - 8.6 weeks), 88% healed, 8% improved and 4% did not
heal. As the average time between stress fracture symptom onset and beginning treatment was
21 weeks (navicular - approximately 32 weeks), time to healing with the addition of electric field
stimulation appeared to be a substantial improvement (13 and 24 weeks) on healing without
stimulation. While the results were encouraging, the study controlled for neither a placebo
effect, nor stress fracture type or prior healing.

Although all create potentially effective electric fields in tissue, CCEFS has distinct
advantages over direct current (DC) or pulsed electromagnetic field (PEMF) stimulation of bone.
DC stimulation (24 hour stimulation) is an invasive approach, necessitating surgery. PEMF
(recommended 3-10 hours per day) generates an electromagnetic field from a rigid, unwieldy
coil, using a heavy power supply requiring daily recharging. A CCEF device, by contrast, is
small and light weight (4 oz); using a 9 Volt battery and small, flexible, gel electrodes. CCEFS
has been shown to stimulate significantly more DNA production from bone cells than
PEMF (13). The difference in effect is likely due to different mechanisms of action, PEMF being
reliant on activation of finite intracellular stores of calcium while CCEFS can utilize the infinite
amount of calcium available in the extracellular space (13).

Current opinion is that mechanical loads on the skeleton are transduced to bone cells by
strain-induced fluid flow within the bone tissue. Membrane shear stress, a tangential force
generated by fluid flow, is known to stimulate the reorganization of the cytoskeleton and
increase expression of cyclooxygenase-2 following inositol-triphosphate-mediated intracellular
calcium release(17, 29), with a similar increase in activated calmodulin that is observed with
CCEFS(11, 13). Streaming potentials, detectable from the surface of loaded bone, are
measurable evidence of fluid flow across bone cortices. It is conceivable that electric field
stimulation of bone achieves its effect by way of fluid flow electroosmosis, an electrokinetic
relative of streaming potentials. That is, flow of the electrolytic bone fluid may arise as a
consequence of the application of an electric field to bone. That low intensity pulsed ultrasound
stimulation (LIPUS) appears to accelerate the healing of frank fractures and complex tibial
fractures (24, 25) suggests an ability of sound waves to also perturb bone fluid. We
hypothesised that the passive application of an electric field to bone would force fluid to flow
through the interstitial spaces and channels, stimulate osteogenesis and, ultimately, stress
fracture healing. It is possible that both electrochemical and mechanical mechanisms are
involved in the transduction of the osteogenic signal. It is unknown if LIPUS stimulates stress
fracture healing. The short treatment time of 20 minutes per day suggests it may be an appealing
possible alternative to CCEFS.

The lack of generalized effect of the CCEF device to accelerate healing in our cohort may
have arisen from an intrinsic threshold rate of stress fracture healing below which extrinsic
stimuli failed to promote further affect. It is noteworthy that previous reports of the time
required for tibial stress fracture healing of 12 ±7 weeks (84 days) grossly exceed the average
time taken for our study subjects to heal (roughly 27 days from treatment initiation or 55 days
from injury), regardless of device allocation. Apriori power calculations based on finding a
between-group difference in healing time of three weeks may have constrained the sensitivity of
our statistical analysis. It is possible that the close monitoring of subjects, the constant
encouragement to minimize weight bearing training during treatment, the provision of calcium
supplements, and the discouragement from ingesting NSAIDS, optimized rate of healing for all
subjects. Under such conditions, subtle differences in healing rates become very difficult to
detect, and arguably clinically insignificant. This would likely not be the case for more
exceptional fractures (frank, non-unions and pseudarthroses) for which healing times are more
prolonged, and significant CCEFS efficacy has been reported. Our findings generate the
hypothesis that more severe tibial stress fracture may derive considerable benefit from CCEFS, a
premise that remains to be tested with larger subject numbers.

Conclusions

Based on primary between-group comparisons, we cannot conclude that treatment with
CCEFS accelerated tibial stress fracture healing in our sample. There is compelling evidence,
however, that CCEFS accelerated healing in the more severe cases, and that greater compliance
and reduced weight bearing activity during healing promoted efficacy.

Our analysis likely reflects the real-life efficacy of CCEFS on the healing of relatively
minor tibial stress fractures of the average individual. It is possible, however, that the higher
stakes associated with healing for elite or more severely injured athletes or recruits may inspire
superior treatment compliance, and justify the use of CCEFS when even minor reductions in
days to healing could mean the difference between an ability or inability to compete in a once-in-
a-lifetime event.
References


Table 1. Means \(\pm SD\) of characteristics of stress fracture subjects treated with active and placebo electric field stimulation

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Male (n = 19)</th>
<th></th>
<th>Female (n = 24)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active (n = 8)</td>
<td>Placebo (n = 11)</td>
<td>Active (n = 14)</td>
<td>Placebo (n = 10)</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>28.33 (\pm) 7.68</td>
<td>26.09 (\pm) 7.99</td>
<td>27.79 (\pm) 7.93</td>
<td>23.90 (\pm) 6.23</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>178.17 (\pm) 5.43</td>
<td>178.60 (\pm) 7.24</td>
<td>164.69 (\pm) 4.90</td>
<td>166.05 (\pm) 6.95</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78.25 (\pm) 8.35</td>
<td>80.54 (\pm) 7.53</td>
<td>61.04 (\pm) 9.61</td>
<td>57.41 (\pm) 4.68</td>
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<tr>
<td>Body Mass Index (kg/cm(^2))</td>
<td>24.65 (\pm) 2.40</td>
<td>25.26 (\pm) 2.03</td>
<td>22.56 (\pm) 3.79</td>
<td>20.83 (\pm) 1.41</td>
</tr>
<tr>
<td>Daily calcium intake (mg)</td>
<td>1543.30 (\pm) 759.30(^c)</td>
<td>1432.10 (\pm) 811.20(^c)</td>
<td>1013.2 (\pm) 437.60</td>
<td>881.0 (\pm) 207.6</td>
</tr>
<tr>
<td>Percent fat</td>
<td>18.40 (\pm) 5.69</td>
<td>15.71 (\pm) 6.59</td>
<td>33.76 (\pm) 7.49</td>
<td>25.10 (\pm) 5.06(^a)</td>
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<td>Percent lean mass</td>
<td>78.26 (\pm) 5.30</td>
<td>80.51 (\pm) 6.23</td>
<td>62.65 (\pm) 7.20</td>
<td>70.37 (\pm) 5.01(^b)</td>
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<td>BUA (dB/MHz)</td>
<td>102.63 (\pm) 14.06</td>
<td>114.16 (\pm) 21.21</td>
<td>91.95 (\pm) 16.29</td>
<td>93.75 (\pm) 15.84</td>
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<td>BMD composite (z score average)</td>
<td>0.73 (\pm) 1.20</td>
<td>0.88 (\pm) 1.00</td>
<td>0.55 (\pm) 1.2</td>
<td>-0.26 (\pm) 0.60</td>
</tr>
</tbody>
</table>

\(^a\) Female Active > Placebo, p = 0.02, \(^b\) Female Active < Placebo, p = 0.03, \(^c\) Men > Women, p = 0.02. BUA - broadband ultrasound attenuation, BMD - bone mineral density
Table 2. Primary sport/activity of tibial stress fracture subjects according to sex.

<table>
<thead>
<tr>
<th>Sport/Activity</th>
<th>Male (n = 19)</th>
<th>Female (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance running</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Sprinting</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Aerobics</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Triathlon</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Team sport (football, netball, ultimate frisbee)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Boxing</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 3. Comparison between treatment and placebo group injury severities and compliance scores according to sex (means \(\bar{x}\)SD).

<table>
<thead>
<tr>
<th></th>
<th>Male (n = 19)</th>
<th></th>
<th>Female (n = 24)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active</td>
<td>Placebo</td>
<td>Total men</td>
<td>Active</td>
</tr>
<tr>
<td>Clinical injury severity (pain) score</td>
<td>11.1 (\bar{x}) 4.8</td>
<td>12.8 (\bar{x}) 3.0</td>
<td>12 (\bar{x}) 3.9</td>
<td>13.3 (\bar{x}) 3.2</td>
</tr>
<tr>
<td>Radiological injury severity score</td>
<td>4.9 (\bar{x}) 1.6</td>
<td>5.5 (\bar{x}) 2.4</td>
<td>5.2 (\bar{x}) 2.0</td>
<td>4.3 (\bar{x}) 1.8</td>
</tr>
<tr>
<td>Delay to begin intervention (days)</td>
<td>34 (\bar{x}) 22.8</td>
<td>18 (\bar{x}) 16.2</td>
<td>25 (\bar{x}) 20.6</td>
<td>33 (\bar{x}) 29.6</td>
</tr>
<tr>
<td>Device use compliance (Physician Test Meter hours/treatment days)</td>
<td>13.5 (\bar{x}) 5.8</td>
<td>16.9 (\bar{x}) 5.2</td>
<td>15.3 (\bar{x}) 5.6</td>
<td>14 (\bar{x}) 4.9</td>
</tr>
<tr>
<td>Rest compliance (Degree of continued weight bearing activity)</td>
<td>1.1 (\bar{x}) 0.9</td>
<td>1.2 (\bar{x}) 0.4</td>
<td>1.1 (\bar{x}) 0.7</td>
<td>1.0 (\bar{x}) 0.7</td>
</tr>
</tbody>
</table>
Table 4. Whole group and sex-specific tibial stress fracture healing times according to device status (means ± SD).

<table>
<thead>
<tr>
<th></th>
<th>All subjects (n = 43)</th>
<th>Male (n = 19)</th>
<th>Female (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active (n = 22)</td>
<td>Placebo (n = 21)</td>
<td>Active (n = 8)</td>
</tr>
<tr>
<td>Time to healing from start of treatment (days)</td>
<td>29.0 ± 15.8</td>
<td>25.9 ± 13.5</td>
<td>20.6 ± 13.9</td>
</tr>
<tr>
<td>Time to healing from injury date (days)</td>
<td>60.7 ± 31.5</td>
<td>48.1 ± 24.3</td>
<td>52 ± 30.8</td>
</tr>
<tr>
<td>Actual stimulation time (24 hr periods)</td>
<td>15.2 ± 9.4</td>
<td>16.2 ± 7.7</td>
<td>10 ± 6.2</td>
</tr>
</tbody>
</table>

\(a\) Females > males (p = 0.04), \(b\) Females > males (p = 0.05)
Figure Legends

1. The capacitively coupled electric field stimulator (OrthoPak® Bone Growth Stimulator System, EBI, Hackensack, NJ) in situ for the treatment of mid-to-distal third posteromedial tibial stress fracture
2. CONSORT diagram of tibial stress fracture subject flow

Volunteers assessed for eligibility: n = 81
  Male n = 38
  Female n = 43

Randomised:
  Male n = 21
  Female n = 29

Allocated to intervention:
  Male n = 9
  Female n = 13

Discontinued intervention:
  Male n = 0
  Female n = 0

Analysed intervention:
  Male n = 8
  Female n = 14
  Excluded from analysis:
    Male n = 1 (extremity oth
    Female n = 1 (cervical hemangioma)

Allocated to control:
  Male n = 12
  Female n = 14

Discontinued control:
  Male n = 0
  Female n = 2 (lost interest)

Analysed control:
  Male n = 11
  Female n = 10
  Excluded from analysis:
    Male n = 1 (medial compartmental stress fracture)
    Female n = 2 (medial compartmental pain syndrome type I)

Excluded:
  Male n = 17
  Reason for exclusion:
    3 x wrong fracture site
    4 x shin pain but no fracture
    3 x too long time injury
    3 x subject did not want to participate
    2 x too young
    1 x considered too narrow
    Female n = 14
  Reason for exclusion:
    4 x wrong fracture site
    3 x too long time injury
    3 x subject did not want to participate
    2 x too young
    1 x shin pain but no fracture
    1 x concerned about radiation from imaging
3. Mean natural log time to heal from start of treatment for male and female tibial stress fracture subjects in placebo (0) and treatment (1) groups. A sex difference in time to healing is evident in the treatment (p < 0.05) but not placebo group.