**NEUROMUSCULAR ELECTRICAL STIMULATION ENHANCES FRACTURE HEALING**

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**INTRODUCTION:**
Neuromuscular electrical stimulation (NMES) therapy has often been used for muscle strengthening, maintenance of muscle mass and strength during prolonged periods of immobilization, and control of edema after injury. The purpose of the present study was to evaluate the effect of NMES therapy on fracture healing, using an animal model.

**METHODS:**
The study protocol was approved and followed by the Institutional Animal Care and Use Committee of the author’s institution. Twenty-four rabbits received unilateral, transverse, mid-tibial, 3mm gapped osteotomies that were stabilized with double-bar external fixators. With the aim to simulate the venous stasis and soft tissue edema that is common to acute tibial fractures, the left femoral vein was ligated in all animals. The animals were divided into two study groups: Animals in Group I (study group, n=11) received NMES, while animals in Group II (control group, n=13) did not receive any treatment. With all animals placed in hanging slings, and thirty minutes after administration of analgesia (Morphine, 5 mg/kg), only animals in Group I (study group) received a dose of 1 hour of daily NMES, starting on the fourth post-operative day, for a period of twenty-five days. For NMES, two surface electrodes (2-cm in diameter) were adhered to the shaved skin using elastic adhesive bandages and electrode cream: one above the patellar tendon and another around the lateral thigh. Electric current, with an approximate amplitude of 25 mA, a pulse width of 50 µsec, and a pulse rate of 4 Hz was applied using an EMS+2 Neuromuscular Stimulator (Rehabicare, New Brighton, MN). The electrical stimulation was given in cycles of 20 seconds (a progressive increase in intensity for 5 seconds, peak intensity for 10 seconds, and a progressive decrease in intensity for 5 seconds) with resting intervals of 15 seconds.

Callus development was qualitatively evaluated with a biweekly peripheral computed tomography (pQCT: XCT 3000, Stratec, Pforzheim, Germany), under general anesthesia. A bone section of 5 mm in length (including the 3-mm gap in the middle) was analyzed through three consecutive transverse pQCT scans of 1.1 mm in thickness and 0.1 x 0.1 mm in pixel size. The mineral content (mg/mm), mineralized callus area (mm²), and bone mineral density (mg/cm³) at the gap level, and also the total mineral content (mg/mm) were calculated. In order to assess progression of remodeling, areas of higher density bone (> 650 mg/cm³) within the callus were measured and separated from areas of lower mineral density. At 8 weeks after the index procedure, both tibias were subject to torsional failure tests at a rate of 4.5°/sec. Four torsional parameters were derived from torque displacement curves, and normalized to that of the contralateral intact tibia: maximum torque, stiffness, angular displacement at maximum torque, and energy required to failure. Student t-test was used for comparisons between groups. A p value of less than 0.05 was considered as significant.

**RESULTS:**
Mineral content and mineralized callus area at the osteotomy site increased progressively in both groups, starting from the second post-operative week (Fig. 1). After the forth post-operative week, the rate of mineralization and the area of mineralized callus increased at a higher rate in the study group, compared to the control group, reaching statistical significance at the sixth week. The average mineral content at the osteotomy site, measured at the sixth and eighth post-operative weeks, were 33.4 ± 13.2 mg/mm and 43.8 ± 11.9 mg/mm, respectively, in the study group. These values were significantly higher than those obtained in the control group (23.6 ± 12.5 mg/mm at six weeks, p=0.04; 33.5 ± 8.6 mg/mm at eight weeks, p=0.01) (Fig. 1). The average area of mineralized callus at the osteotomy site measured at the sixth and eighth post-operative weeks in the study group were 58.7 ± 19.7 mm² and 64.1 ± 14.3 mm², respectively. These values were significantly higher than those obtained in the control group (42.4 ± 19.3 mm² at six weeks, p=0.03; 50.4 ± 11.7 mm² at eight weeks, p=0.009). No significant differences in area or mineral content of highly mineralized callus (>650 mg/cm³) were observed between the groups before the eighth week. The average area and mineral content of highly mineralized callus measured at the eight post-operative week in the study group were significantly higher than those measured in the control group (area: 35.8 ± 15.5 mm² vs. 25.2 ± 2.6 mm², respectively, p=0.02; mineral content: 29.4 ± 12.9 mg/mm vs. 20.7 ± 8.4 mg/mm, respectively, p=0.03).

**DISCUSSION:**
The present study demonstrated that the application of NMES therapy to the venous congested limb during the early fracture-healing period enhanced callus formation and mineralization. As a result, the biomechanical properties of the healing bone can be improved.

Several hypothesis can explain the results observed in the present study: Repeated muscle contraction could increase the arterial blood supply to the fracture site, either by improving vascular perfusion to the skeletal muscle or increasing venous return. Additionally, muscle contraction induced by NMES could generate interfragmentary motion at the fracture site. In light of the results of the present study, more investigation is warranted in order to elucidate the mechanisms by which NMES enhances fracture healing, as well as to find the optimum frequency, intensity, and duration of the treatment.

![](image1)

**Fig. 1.** Values of mineral content obtained progressively at the 3-mm gap (mg/mm). Horizontal line indicates mean value of contralateral intact bone value, bar indicates standard error. * indicates p<0.05.

The study group exhibited superior biomechanical properties than the control group (Fig. 2). The study group showed 29% higher stiffness (p=0.032), 62% higher maximum torque (p=0.0006), 34% larger angular displacement at maximum torque (p=0.008), and 124% larger energy required for failure (p=0.0001) than the control group.

![](image2)

**Fig. 2.** Biomechanical properties measured eight weeks after the index procedure. A significant difference between the study group and the control group was observed in all parameters tested.

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