INTRODUCTION: Pulsed Electromagnetic Fields (PEMF) have proven to be effective in accelerating healing in delayed unions and in healing non-unions [1]. The effectiveness of a new PEMF signal which requires less power than the existing devices was demonstrated in animal models [2,3]. However, the optimal dose of the stimulation has yet to be determined. The purpose of this study was to investigate the optimal time duration for exposure of the new PEMF signal using a delayed union model in the canine mid-tibia.

METHODS: Standardized transverse mid-diaphyseal tibial osteotomies were performed unilaterally on 12 adult mixed breed dogs. The osteotomies were stabilized with a 2 mm gap and fixed using a rigid custom-made unilateral 6 halfpin external fixator. An EBI PEMF stimulation system using an asymmetric wave form varying from +2.5 to -135 mVs pulsed at 1.5 Hz in 30 ms bursts [2,3] was applied to the osteotomy site 7 days a week (Fig. 1). The stimulation was started 4 weeks after surgery and lasted for 8 weeks until euthanasia. The animals were divided into PEMF-stimulated (n=6) and non-stimulated (n=6) groups. In the PEMF-stimulated group (PEMF 4 Hrs group), the signal generator was activated 4 hours per treatment, while no signal was generated in the non-stimulated control group. Function was assessed by dynamic weight bearing during gait at 4, 8, and 12 weeks after surgery. Radiographic examination was done every 2 weeks after surgery. Areas of periosteal callus were measured on plain radiographs. Animals were euthanized 12 weeks after surgery. All procedures were approved by the institutional animal committee. Axial torsion was performed on the osteotomized tibiae using an MTS mechanical testing machine. Longitudinal and transverse undecalcified sections were prepared after mechanical testing for the histological study (Fig. 2). The results were also compared to data obtained from the study using identical procedures, with the exception that the daily PEMF stimulation time was 1 hour instead of 4 hours (PEMF 1 Hr group) [3]. Between-group data and time-related data within each group were analyzed by ANOVA with post-hoc t-test. Significance level was set at p<0.05.

RESULTS: Gait analysis (Fig. 3): Both in the PEMF 1 Hr and PEMF 4 Hrs groups, dynamic weight bearing increased significantly from 4 to 8 weeks following surgery. In the control group, a significant increase occurred only from 8 to 12 weeks. At 8 weeks, weight bearing both in the PEMF 1 Hr and PEMF 4 Hrs groups was significantly higher than that in the control group. There was no significant difference between the PEMF 1 Hr and PEMF 4 Hrs groups.

Radiographic analysis (Fig. 3): There was a significant increase in the periosteal callus area after 4 weeks in both of the PEMF stimulated groups but not in the control group. At 12 weeks, the periosteal callus area in the PEMF 4 Hrs group was significantly higher than that of the control group. There was no significant difference between PEMF 1 Hr and PEMF 4 Hrs groups.

Mechanical testing: Maximum torque of the PEMF 4 Hrs, PEMF 1 Hr, and control groups was 21.4 ± 6.6, 22.4 ± 3.4, and 18.6 ± 6.4 Nm (mean ± SD), respectively. Torsional stiffness of the PEMF 4 Hrs, PEMF 1 Hr, and control groups was 132.0 ± 20.5, 138.8 ± 25.6, and 89.8 ± 29.6 Nm/rad, respectively. A significant increase in torsional stiffness was observed in both the PEMF stimulation groups compared to the control group. There was no significant difference between PEMF 1 Hr and PEMF 4 Hrs groups.

Histological studies (Fig. 4): The mineral apposition rate was significantly higher in the PEMF 1 Hr group than in the control group in the cortex 3 and 5 mm away from the osteotomy line. The cortical bone porosity in both PEMF stimulation groups was significantly decreased compared to the control group in the cortex 1, 3, 5, and 10 mm away from the osteotomy line. At 3 mm away from the osteotomy line, the porosity in the PEMF 4 Hrs group was significantly decreased compared with the PEMF 1 Hr group.

DISCUSSION: This study demonstrated that there was no additional gain in the studied osteotomy healing augmentation by increasing the stimulation time from 1 hour to 4 hours, even though some bone histomorphometric parameters showed some benefits with the longer stimulation. Fredericks et al. studied the effects of the same PEMF signal on bone healing in a rabbit tibial osteotomy model and found that 1 hour stimulation was more beneficial compared to 30 minute stimulation [2]. The same report also introduced a rat endochondral bone induction model using the same PEMF signal performed by Aaron (unpublished) demonstrating that stimulation of bone formation was significantly greater with 1 hour daily stimulation than with 8 hours in a histomorphometric study. In addition to the less energy requirement of the new PEMF signal used in the present study, this signal requires shorter daily treatment period with the same effect gained with the longer treatment time. With no additional gain under prolonged treatment, it is important to establish the optimal dose in terms of PEMF treatment time in different bone fracture healing conditions to save cost, reduce co-morbidity and minimize any potential side effects to the normal tissue adjacent to the field of stimulation.

REFERENCES:

**EBI, Parsippany, New Jersey.

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