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ORIGINAL ARTICLE

Effects of pulsed electromagnetic field therapy at different frequencies and durations on rotator cuff tendon-to-bone healing in a rat model

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Background: Rotator cuff tears affect millions of individuals each year, often requiring surgical intervention. However, repair failure remains common. We have previously shown that pulsed electromagnetic field (PEMF) therapy improved tendon-to-bone healing in a rat rotator cuff model. The purpose of this study was to determine the influence of both PEMF frequency and exposure time on rotator cuff healing.
Methods: Two hundred ten Sprague-Dawley rats underwent acute bilateral supraspinatus injury and repair followed by either Physio-Stim PEMF or high-frequency PEMF therapy for 1, 3, or 6 hours daily. Control animals did not receive PEMF therapy. Mechanical and histologic properties were assessed at 4, 8, and 16 weeks.
Results: Improvements in different mechanical properties at various endpoints were identified for all treatment modalities when compared with untreated animals, regardless of PEMF frequency or duration. Of note, 1 hour of Physio-Stim treatment showed significant improvements in tendon mechanical properties across all time points, including increases in both modulus and stiffness as early as 4 weeks. Collagen organization improved for several of the treatment groups compared with controls. In addition, improvements in type I collagen and fibronectin expression were identified with PEMF treatment. An important finding was that no adverse effects were identified in any mechanical or histologic property.
Conclusions: Overall, our results suggest that PEMF therapy has a positive effect on rat rotator cuff healing for each electromagnetic fundamental pulse frequency and treatment duration tested in this study.
Level of evidence: Basic Science Study; Biomechanics and/or Histology

Keywords: PEMF; supraspinatus repair; rat; animal model; rotator cuff; tendon healing

Rotator cuff tears affect millions of individuals each year, often requiring surgical intervention. Although recent advancements in surgical methods and rehabilitation protocols have improved clinical results, rotator cuff repair failure is still common.[6] Contributing to repair failure is the nature of injured tissue, which tends to be disorganized and fibrotic.

The University of Pennsylvania Institutional Animal Care and Use Committee approved this study (No. 805274).

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This scar tissue is unable to successfully re-create native tendon-to-bone properties after repair. To enhance native tissue healing and improve surgical outcomes, various noninvasive therapeutic methods have been used postoperatively, including ultrasound and shock wave therapy.[16,21] Advantages of noninvasive therapeutic devices include their ease of use, relatively low cost, and ability to be brought into the patient's home instead of requiring frequent visits to the clinic. In addition, their use as a postoperative adjuvant therapy does not interfere with surgical techniques or standard rehabilitation protocols.

Pulsed electromagnetic field (PEMF) therapy has been approved by the US Food and Drug Administration (FDA) for the treatment of fracture nonunions and for the enhancement of bone formation after lumbar and cervical spine fusion surgery. Because PEMF therapy has been shown to decrease markers of inflammation, it is also of interest as a potential therapeutic method in soft tissue healing environments. PEMF therapy has been used in clinical studies to treat osteoarthritis, epicondylitis, and rotator cuff tears.[9,18,19,26] Three months after surgical repair, patients with small or medium rotator cuff tears showed improved range of motion after receiving PEMF therapy when compared with patients receiving placebo. To investigate the structural and functional effects of PEMF therapy on tendon-to-bone healing, we have previously used PEMF therapy in a rat rotator cuff injury and transosseous repair model. The results showed that PEMF therapy improved healing. These improvements included increased bone volume fraction, trabecular thickness, and bone mineral density at the repair site, similar to bone changes seen in other bone-healing PEMF applications.[2,10] In addition, the PEMF-treated groups showed improvements in tendon tissue properties including a 100% increase in tendon modulus after 4 weeks, as well as improved collagen alignment at later time points.[24]

However, PEMF signal characteristics typically vary between studies and applications in terms of waveform type, signal intensity, and treatment duration. Several studies have identified differences in cell and tissue response to PEMF therapy of varying parameters, including frequency and treatment duration. For example, the formation of osteoclast-like cells in a culture of bone marrow cells, as well as concentrations of secreted inflammatory cytokines, can be either enhanced or suppressed by manipulating induced electric field intensity.[3] Similarly, osteogenic differentiation of human mesenchymal stem cells differed following exposure to a variety of PEMF frequencies.[17] Tendon cells isolated from human semitendinosus and gracilis tendons displayed altered regulation of gene expression dependent on field intensity, duration, and number of exposures.[4] In a rat model of Achilles tendon injury and repair, alterations in PEMF frequency and signal amplitude affected tendon strength after repair.[22] However, the effect of frequency and treatment duration has not yet been evaluated in our rat rotator cuff injury and repair model.

Therefore, the objective of this study was to determine the influence of both PEMF frequency and exposure time on rotator cuff healing. We used Physio-Stim PEMF therapy (PS; Orthofix, Lewisville, TX, USA), as well as high-frequency (HF) Physio-Stim PEMF therapy (Orthofix), which is similar in all aspects to PS with the exception of a higher fundamental frequency. Both treatments were tested using 1-, 3-, and 6-hour daily durations. We hypothesized that a PEMF signal with a higher fundamental frequency and longer daily treatment duration would (1) lead to further improvements in mechanical properties and (2) improve tissue morphology including cell shape, cellularity, and collagen fiber organization.

Materials and methods

The methods used in this study, including animal care, surgical techniques, tendon mechanics, and tendon histology, are identical to those in our previously published work.[24]

Study design

In this study, we used 210 adult male Sprague-Dawley rats (400-450 g) (including 60 from our previous study[24]). The animals were housed in a conventional facility with 12-hour light-dark cycles and were fed standard rat chow ad libitum. They underwent bilateral acute supraspinatus injury and repair[1] followed by randomization into treatment groups, receiving either Physio-Stim PEMF therapy (PS) or HF PEMF therapy (similar to PS but with a higher fundamental frequency) for 1, 3, or 6 hours daily. Control animals did not receive PEMF therapy (non-PEMF group). The control and 3-hour PS groups used in this study were taken from our previously published work.

The animals were killed humanely at 4, 8, or 16 weeks ($n = 10$ per group per time point). At the time of death, the right shoulders ($n = 7$ per group per time point) were immediately dissected, fixed in formalin, and processed for histologic analysis. The left shoulders ($n = 10$ per group per time point) were left intact, and the animals were frozen at –20°C and thawed for dissection at the time of mechanical testing.

Detachment and repair surgery

The animals were subjected to bilateral supraspinatus detachment and repair as described. For analgesia, buprenorphine (0.05 mg/kg) was administered subcutaneously 30 minutes prior to surgery, 6-8 hours postoperatively, and then every 8-12 hours for the next 48 hours. In brief, with the arm held in external rotation and adduction, the supraspinatus tendon was exposed. The tendon was grasped with a simple grasping stitch using 5-0 polypropylene suture (Surgipro II; Covidien, Mansfield, MA, USA) and was sharply transected from its bony insertion. For repair, a 5-mm-diameter high-speed bur (Multipro 395; Dremel, Mount Prospect, IL, USA) was used to remove the remaining fibrocartilage from the footprint of the tendon insertion site. A 0.5-mm bone tunnel was drilled from anterior to posterior through the greater tuberosity. Suture was then passed through the bone tunnel and tied, securing the supraspinatus to the footprint. The wound was flushed with saline solution, and the deltoid and skin were closed with 4-0 Vicryl suture (Ethicon, Bridgewater, NJ, USA).