Combined Magnetic Fields Accelerate Bone-tendon Junction Healing

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INTRUDUCTION: Bone-tendon (B-T) junction injury is a common clinical finding, especially among young orthopaedics and sports medicine patients involved in competitive athletic events. This injury may involve different tendons and ligaments, such as the anterior cruciate ligament, patellar tendon, rotator cuff insertion, and achilles tendon. The bone to tendon junction, or the enthesis, involves all major connective tissues, when injury occurred at this anatomical site, it is usually difficult for it to heal. There is also a lack of effective adjunct therapy after surgical repair to improve treatment outcome for successful functional recovery. It is well known that different forms of biophysical stimulation, such as combined magnetic field (CMF), have positive effect on musculoskeletal tissue repair after injury because of its enhancing effect on new bone formation and regeneration. This mode of stimulation may have significant enhancing effects on bone to tendon healing through a positive bone formation pathway. These objectives of this study are to investigate the effect of CMF therapy on bone-tendon healing and to explore the enhancing mechanism in the hope of optimizing the therapeutic regimen for clinical application.

METHODS: Standard partial patellectomy surgery was conducted in 96 mature rabbits which were divided into CMF treatment group and placebo treatment group (control group). Daily 30 minutes CMF treatment was delivered by the stimulation coil with its stimulation signal focal point placed close to the patella-patellar tendon (PPT) junction site in the rabbit immobilized in a specially made wooden box (Fig. 1). The treatment started 3 days after surgery until animal euthanasia at postoperative week 4, 8, 12 and 16. Then the PPT complex from each animal was harvested for evaluation using radiography (Fig. 2), peripheral quantitative computational tomography (pQCT) and tensile strength of quadriceps-patella-patellar tendon-tibia (QPPTT). The maximum tensile force and energy at failure were determined. The maximum tensile force was then divided by the cross-sectional area (CSA) of the bone-tendon (B-T) junction healing interface to obtain the tensile strength at failure, i.e. the ultimate strength. All the above quantitative data were analyzed statistically using a two-factor repeated measure ANOVA to investigate the effects of the independent variables (experiment time at two levels and treatment at two levels). In case there was no interaction found between the main effects was not significant ($p>0.05$), a LSD's multiple comparisons test was utilized for the significant main effects. The significance level was set as at $p \leq 0.05$. All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) 17.0 software program (SPSS Inc, Chicago, IL, USA).

RESULTS: 1) The newly formed bone in PPT junction presented gradual outgrowth in both the treatment and the control groups. The area and length of these new bones increased with healing time in both groups. There were significant differences in the area and length of the new bone between treatment and control group at 4, 8, 12 and 16 weeks respectively ($p<0.05$). 2) BMD, BMC and BV of the new bone in two groups had a gradual increase trend with the healing time. There were no significant difference in BMD, BMC and BV of new bone between treatment and control group at 4 weeks ($p>0.05$), but these values in treatment group were higher than control group at 8, 12 and 16 weeks ($p<0.05$) respectively. 3) The mechanical property, failure load, the ultimate strength and energy at failure, increased with the healing time. There were no significant differences in failure load, the ultimate strength and energy at failure between treatment and the control group at 4 weeks ($p>0.05$), but the tensile properties were significantly higher in treatment group than those in the control at 8, 12, 16 weeks ($p<0.05$). Exceptionally, there was no significant difference in ultimate stress between treatment and control group at 16 weeks ($p>0.05$). (Table)

DISCUSSION: This study firstly showed that CMF were able to accelerate B-T junction repair in a partial patellectomy model in rabbits. We assumed that under the treatment of CMF, the healing of PPT junction would proceed into the remodeling stage with enhanced healing to promote loading thereby improving its mechanical strength and maximizing functional recovery of the knee joint. Through enhanced bone formation and maturation, CMF treatment improved the mechanical property of the reconstructed PPT and thus allowed adequate earlier rehab exercise which would lead to better functional recovery. This study also showed that there were larger bone volume and early remodeling in treatment group. The mechanical strength of the PPT junction in treatment group could only reach 66.4% of that in contralateral intact specimen even at 16 weeks. However, our previous studies [1,2] using the same model but different stimulation of the low-intensity pulsed ultrasound stimulation (LIPUS) could only produce on average, 58.7% of the contralateral intact control at 16 weeks. When compared with LIPUS treatment, the healing quality of PPT reattachment with CMF therapy can achieve at least the similar effect and may even improve slightly. Further detailed histomorphological analyses will help to identify the enhancement mechanism under CMF stimulation which will optimize the CMF therapy for clinical applications in PPT and other B-T junction healing.

Conclusion: Daily 30 minutes CMF therapy was found to significantly accelerate the PPT junction repair with significantly improved tensile strength when compared to the control group without CMF stimulation.

Fig.1 The rabbit is immobilized in a specially made wooden box when treated by CMF.

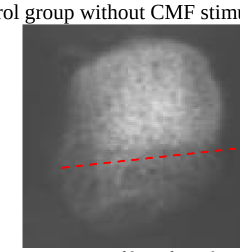

Fig.2 X-ray film of week 16 patella at antero-posterior view (Red line represent ostectomy section).

Table The healing properties of patella-patellar tendon (PPT) junction at week 4, 8, 12 and 16 (Data presented as Mean±SD) (n=12)

Measurements		Groups	Healing Time			
			Week 4	**Week 8**	**Week 12**	**Week 16**
Newly Formed Bone	Area (mm^2)[a,b]	CMF	2.95±0.90*	8.20±1.62*	13.17±0.71*	20.58±1.99*
		Control	1.92±0.69	5.52±1.23	10.2±1.33	15.8±0.88
	Length (mm)[a,b]	CMF	0.88±0.22*	2.00±0.22*	3.11±0.29*	4.47±1.37*
		Control	0.67±0.35	1.10±0.27	2.18±0.50	2.94±1.07
	BMD (mg/cm^3)[A,B]	CMF	0.4888± 0.0837	0.5597± 0.0678*	0.6399± 0.0497*	0.6361± 0.0290*
		Control	0.4121± 0.0683	0.4590± 0.0404	0.5349± 0.0546	0.5516± 0.0231
	BMC (mg)[a,b]	CMF	5.94±1.32	20.60±9.65*	28.77±15.77*	44.71±20.23*
		Control	2.67±0.66	9.11±3.24	14.11±8.09	20.14±11.28
	BV(mm3)[a,b]	CMF	10.59±3.33	33.25±14.09 *	46.19±16.11*	61.32±9.10*
		Control	5.89±1.05	16.29±6.58	32.94±12.06	42.11±10.51
Cross-sectional Area (mm^2)		CMF	15.28±5.25	19.54±6.69	29.58±9.55*	29.12±8.06
		Control	14.89±5.88	16.13±4.71	21.25±3.33	30.56±9.78
Tensile Properties	Failure Load (N)[A,B]	CMF	62.8±35.8	144.6±29.3*	229.2±79.4*	270.0±59.4*
		Control	56.9±13.3	95.4±26.5	154.2±40.9	175.1±65.6
	Ultimate strength (N/mm^2)[A,B]	CMF	4.81±1.10	6.92±0.75*	8.27±1.21*	8.56±0.47
		Control	3.99±1.56	5.23±0.85	6.57±1.16	7.48±0.99
	Energy at Failure (J)[A,b]	CMF	0.148± 0.026	0.441± 0.148*	0.478± 0.149*	1.257± 0.501**
		Control	0.090± 0.015	0.239± 0.056	0.268± 0.140	0.535± 0.175

[A]: $p<0.05$ and [a]: $p<0.01$, the effect of healing time factor (Two-Way ANOVA)
[B]: $p<0.05$ and [b]: $p<0.01$, the effect of treatment factor (Two-Way ANOVA)
*: $p<0.05$, compared between CMF group and control at the same healing time point
**: $p<0.01$, compared between CMF group and control at the same healing time point

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REFERENCE: [1] Lu H, Qin L, Fok P, et al. Am J Sports Med. 2006;34(8):1287-1296. [2] Qin L, Lu H, Fok P, et al. Ultrasound Med Biol. 2006; 32(12):1905-1911.