Effects of Functional Electrical Stimulation-Induced Cycling on Bone Mineral Density and Bone Stiffness of the *Tibia* – Preliminary Results

P. Eser, J. Ehwald, E. de Bruin, E. Stüssi
Laboratory for Biomechanics
Swiss Federal Institute of Technology
Wagistr. 4, 8952 Schlieren, Switzerland
eser@biomech.mat.ethz.ch

Ch. Brunner, H. Lechner, D. Michel, G.A. Zäch
Swiss Paraplegic Centre
6207 Nottwil, Switzerland

Abstract - *Bone atrophy in spinal cord injured people (SCI) is amongst other factors caused by immobilisation and is initiated shortly after the injury. The present study measures the effect of an FES-cycling intervention on bone mineral density and bone stiffnesss of the tibia in recently injured SCI.*

Immediately after mobilisation, para- and quadriplegic patients are recruited into an intervention and a control group. The intervention consists of 30 min. FES cycling three times a week. Computer tomography (CT) scans of the tibia diaphysis are taken at the beginning and at the end of the intervention. Bone mineral density (BMD) of the cortical bone are calculated from the CT scans. Phase velocity of transversal waves, which is a measure of the bending stiffness of the tibia is measured monthly during the intervention with the Bending Stiffness Measurement Device (BSMD) developed at our laboratory.

Preliminary results of 14 subjects (6 intervention, 8 control group) show a reduction in tibial cortical BMD of 0-6 % of the initial values within 6 months. The change in tibial phase velocity has been assessed for 20 subjects (10 intervention, 10 control group) and is between –0.6 and +0.1 $ms^{-1}d^{-1}$ over a time period of 5-9 months. Within the intervention group, there is a trend towards a reduced loss of bending stiffness with increasing power output on the bicycle ergometer.

Keywords: spinal cord injury, functional electrical stimulation, bone mineral density, bone stiffness

1. Introduction

Bone mineral loss of the paralysed extremities commencing shortly after the spinal cord injury is a well known phenomenon. This bone mineral loss can be problematic when inadequate fractures caused by minor traumas are associated with it. Both longitudinal [1,2] and cross-sectional [3-6] studies have documented extent and timing of this bone atrophy.

Previous studies have assessed the influence on FES-induced cycling. Several studies found no difference in BMD of the lower limbs between before and after the FES-cycling intervention of 3-12 months [7-10]. However, one study suggests a reduced rate of SCI-induced bone loss and therefore a potential beneficial effect [8], and another study even found an increase in bone density at the proximal tibia of 10 % over one year FES-cycling training [11]. The results of the above studies are based on chronic SCI subjects (time since injury > 2y), except for the study by Hangartner et al. [8], which included two recently injured subjects. Some studies [12,13] suggest that the rate of bone mineral loss is greatest within the first two years after the injury and declines thereafter.

The purpose of the present study was therefore to investigate the effect of FES-cycling on bone atrophy of the tibia in recently injured SCI patients.

As this study is still ongoing, the presented results are preliminary and only represent data from subjects that have already completed the study protocol. Further geometric parameters are calculated from the CT scans, but are not mentioned in this article. This is also the reason that no statistics have yet been performed.

2. Methods

2.1. Subjects

The 20 participants were recently injured para- and quadriplegic patients with lesions above T12 at the Swiss Paraplegic Centre in Nottwil, Switzerland. They entered the intervention or control group as soon as they were mobilised (between 4 and 8 weeks, and in one case 3 months after injury). The study was approved by the Ethical Commitee of the Kanton Luzern, and the subjects gave their written informed consent.

2.2. Intervention

The intervention consisted of 30 min. FES cycling on a StimMaster (ELA, Dayton, Ohio) bicycle ergometer. Surface electrodes were applied to the quadriceps, gluteal, and hamstring muscles of the subjects. The stimulation parameters used were sinuoidal pulse waves at a rate of 30-60 Hz, with a pulse width of 0.3-0.5 ms and a max. amplitude of 140 mA. Participants of the intervention group (n=10) started with only a few minutes electrically stimulated cycling per session until fatigue occurred. Within two to six weeks, all participants could cycle for half an hour. After that, resistance was increased progressively according to the physiological capabilities of each subject. On the remaining two days the intervention subjects performed 30 min. of passive standing. The control group (n=10) performed passive standing on five days per week.

2.3. Bone measurements

Computer tomography (CT) scans of the tibia mid shaft were done (with a Somatom Plus 4) as soon as possible (between 2 and 6 weeks, and 2 to 3 months in 3 cases) after the injury and at the end of the intervention (4-9 months after the first CT scans). BMD was calculated from the CT scans. Reproducibility of BMD values is within 2 % (one tibia measured by 3 operators on the same day).

Phase velocity of transversal waves in the tibia was measured monthly during the intervention. Phase velocity is proportional (by the power of four) to bending stiffness. Bending stiffness is a measure of the relationship between an applied force and the resulting deformation with respect to bending. Phase velocity was measured non-invasively by means of the Bending Stiffness Measurement Device [14-17]. This device measures the phase velocity of transversal waves induced by a small impact of a piezoelectric hammer on the tibia.

2.4. Data analysis

A linear regression of the monthly phase velocity measurements was performed for each subject. The inclination of this regression line, expressed as change in phase velocity per day, was correlated to the total power output each subject accumulated through the training sessions. Although the number of training sessions varied between subjects, the time periods over which the phase velocity was measured agreed with the time period over which the power output was added up.

3. Results

Results of the first 20 subjects (10 intervention group, 10 control group) are given. Changes in BMD of the tibia diaphysis are between +1.5 and –8 % of initial values over a time period of 6 months. The same decrease in BMD is found for the two groups (intervention group: -0.38 ± 0.33 % per month; control group: -0.35 ± 0.36 % per month).

Changes in phase velocity of the tibia for each participant (between 11 and 34 measurements) are between –0.6 and +0.1 $ms^{-1}d^{-1}$ over a time period of 5-9 months. The intervention group shows a decrease of -1.2 ± 4.4 ms^{-1} per month, while the control group shows a decrease of -3.1 ± 4.4 ms^{-1} per month. Figure 1 shows that the largest reductions in phase velocity are found in the control group, which also shows a greater variability.

When the change in phase velocity is plotted against the cumulative power output produced by each participant (Fig. 1), an association of positive changes in phase velocity with high power outputs can be seen.

With the data available at present, no correlation between the changes in BMD and phase velocity can be found.

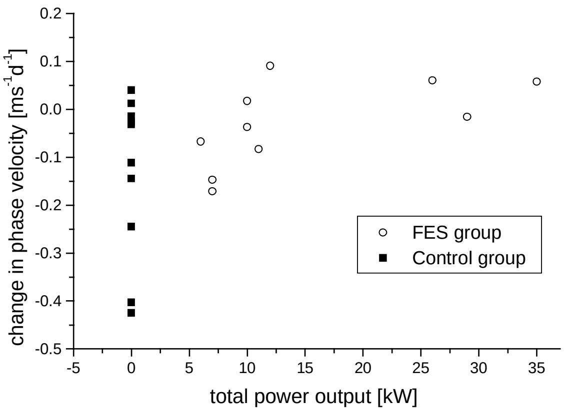

Fig. 1: Change in phase velocity versus cumulative power output in the FES-cycling sessions over the intervention period (5-9 months). As the control group completed no FES-cycling, their power output equals zero.

4. Discussion

For many participants, changes in cortical BMD of the tibia over the intervention period of 5-9 months are small and below the detection limit. The time span of 5-9 months is likely to be too short to detect slow bone mineral losses in cortical bone. Other studies have found a reduced [5,8] or also delayed [1] bone loss in cortical as compared to trabecular bone.

The change in phase velocity reflects a change in bending stiffness, which may be a better indicator for fracture risk than BMD. There is a large variability in phase velocity changes between subjects, which is not surprising considering the many factors influencing bone metabolism and structure before and after the spinal cord injury. However, it seems that an FES-intervention may have a prophylactic effect against bone loss when performed at higher intensities resulting in a larger power output. This result agrees with the study by Mohr et al. [12], who found that a low amount of exercise (6 months of one FES-cycling session per week only) was insufficient to maintain an increase in BMD achieved by FES-cycling performed more often (12 months of 3 sessions per week).

The presented results are preliminary and the collection of further data will show whether the above hypothesis will prove to be correct. The fact that none of the FES-intervention subjects had a large reduction in phase velocity (compared to the control group) is, however, encouraging.

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