Bone Mineral Density After Bicycle Ergometry Training

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ABSTRACT. Leeds EM, Klose KJ, Ganz W, Serafini A, Green BA: Bone mineral density after bicycle ergometry training. Arch Phys Med Rehabil 71:207–209, 1990.

• The effect of functional electrical stimulation (FES) cycle ergometry on bone mineral density (BMD) was investigated in six spinal cord injury (SCI) quadriplegic men. Each subject trained three days a week for six months on an FES cycle ergometer. Pretraining and posttraining BMD measurements of the proximal femur were performed using dual photon absorptiometry. Mean pretraining BMD (percent norm) for the femoral neck, Ward triangle, and trochanter were 66.65, 57.43, and 57.67, respectively. After six months of FES cycle ergometry, mean BMD measurements were 66.15, 57.07, and 55.13, respectively. There was no statistically significant difference between the pretraining and posttraining BMD measurements. All subjects were found to have osteoporotic proximal femurs when BMD was expressed as a percent of their age-matched controls. Bone mineral density measurements were subsequently performed on three additional men with SCI who had exercised for three years with the FES cycle ergometry modality. Their mean BMDs were not significantly different from the experimental group. This study demonstrated that six months of FES cycle ergometry did not produce an increase in BMD.

KEY WORDS: Bicycle ergometry; Bone mineral density; Spinal cord injury

Osteoporosis is an inevitable sequela of traumatic spinal cord injury (SCI). Increased calcium and hydroxyproline excretion during the first six months after SCI signal the loss of bone.[1-4] Iliac crest bone biopsies performed as early as four weeks postinjury demonstrate significant osteoporotic changes.[2,4] During the immediate post-SCI period there is an increased, but unbalanced rate of bone remodeling, with bone resorption occurring at a faster rate than bone formation.[1,5] The new bone matrix is underhydroxylated and hypocalcific.[1,6] Subsequently, normal bone remodeling rates (resorption:formation balance) are observed at one to two years postinjury.[1,5] However, although the already rarified bone is maintained, it does not return to normal.

Hypercalcemia and hypercalciuria have been observed in able-bodied subjects after various periods of bed rest or weightlessness.[7-10] Two studies reported reversal of osteopenia after ambulation, or return to normal gravity.[7,8] The subjects observed in the studies in which reversal of the osteoporotic condition occurred were neurologically intact individuals without the metabolic and neurologic complications associated with traumatic SCI. Similarly, some,[11,12] but not all,[2] studies conducted among the SCI population have reported that weight-bearing activities reduce hypercalcemia. Sir Ludwig Guttmann stated that "As soon as the paraplegic is up in his wheelchair, intensive physiotherapy, including standing and, in particular, sportive activities have been invaluable in combating osteoporosis."[13]

Weight-bearing activities, such as standing and brace walking, have long been promoted as therapies which might retard or reverse SCI-associated osteoporosis.[11,12,14] The experimental portion of our study was conducted to determine if the exercise activity induced by functional electrical stimulation (FES) bicycle ergometry would have an effect on long-term SCI-associated osteoporosis. The results of the experimental portion of the study prompted us to conduct a further assessment of bone status in other SCI individuals. Other physiologic parameters associated with the FES training program will be reported elsewhere.

Table 1: Anthropometric and Neurologic Characteristics of Six Quadriplegic Men

	Age (years)	Postinjury (years)	Injury level	Weight (lbs) Pre-training/ Post-training
S1	24	7	C5	124/116
S2	18	3	C4–C5	136/139
S3	26	5	C5	112/121
S4	27	9	C5–C6	108/102
S5	26	2	C4–C5	168/165
S6	21	5	C5–C6	159/147

METHODS

Subjects

Six quadriplegic men, aged 18 to 27 years, volunteered to participate in a seven-month FES bicycle ergometry exercise program. All of the subjects had had traumatic SCI which resulted in complete neurologic loss of voluntary motor control and sensation in the lower extremities. Table 1 presents the neurologic and anthropometric data for the six subjects.

Training

The FES exercise training was performed on the REGYS I Clinical Rehabilitation System.[a] The technical description of this apparatus was recently described in detail by Ragnarsson and associates.[15] The training protocol consisted of one month

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of resistive knee extension exercise, followed by six months of bicycle ergometry exercise. For knee extension exercise, three surface electrodes were placed on the anterior thigh. Each exercise session consisted of 45 lifts (or until fatigue) in each leg three times a week. After a subject completed a set of 45 lifts, resistance was added by the incremental application of two-pound ankle cuff weights. The amount of weight progressively increased as the subject was able to complete the set with the new resistance. At the end of four weeks of resistive leg training, surface electrodes were placed on the buttocks, and hamstrings, and on the anterior thigh.

Bicycle ergometry exercise sessions were conducted three times a week. Initially, within each session, subjects started with three five-minute rides separated by two five-minute rest periods. As subjects attained this goal, the exercise session increased to three ten-minute rides separated by two five-minute rest periods. Subjects then rode for two 15-minute periods with a five-minute rest between rides. After this, subjects began riding continuously for 30 minutes.

Measures

Dual photon absorptiometry was used to measure bone mineral density (BMD). The BMD measures were made at the Ward triangle, femoral neck, and greater trochanteric region of the proximal femur. The Ward triangle is the space formed by the angle of the trabeculae in the neck of the femur, which is prone to fractures. In the six experimental subjects these measurements were made: (1) before any exercise training and (2) after the subjects had completed seven months of exercise training.

Statistical comparisons were conducted using the multivariate analysis of variance (MANOVA) subprogram of the Statistical Package for the Social Sciences version x ($SPPSS_x$), which permits a repeated measures analysis. An alpha level of .05 was considered statistically significant.

RESULTS

None of the subjects in the exercise training group experienced any adverse effects. Bone mineral density was measured in g/cm^2 but is discussed as percentages of matched healthy individuals (percent norm). Grams per centimeter squared represents the total mineral in a column 1cm in cross-sectional area.[16] Values for BMD differ with regard to fixed factors such as gender, race, height, and weight. Additionally, BMD measures vary according to age, declining over time as part of the normal aging process. Therefore, group data is best presented using relative values. Relative values are obtained by matching subjects to normative distributions that have been established for the able-bodied population.[17] Pretraining and posttraining BMD in g/cm^2 (mean $\pm$SD) for each of the experimental subjects is reported in table 2. Pretraining and posttraining BMD in percent norm (mean $\pm$SD) for each of the experimental subjects is reported in table 3.

The BMD percent norm of the proximal femur for all subjects was found to be below normal before any exercise training. After seven months of exercise training there was no significant difference ($p > .05$) in the BMD for any of the three sites tested on the proximal femur. Mean pretraining BMD of the femoral neck, Ward triangle, and trochanteric region were 66.65, 57.43, and 57.67 percent norm, respectively. Mean posttraining BMD of the same three regions were 66.15, 57.07, and 55.13 percent norm, respectively.

Table 2: Bone Mineral Density (g/cm^2) in Six Quadriplegic Men Before and After Six Months of FES Bicycle Ergometry

	Femoral neck		Ward triangle		Trochanter	
	Before	After	Before	After	Before	After
S1	0.63	0.66	0.43	0.50	0.40	0.40
S2	0.62	0.62	0.44	0.43	0.44	0.43
S3	0.65	0.64	0.56	0.53	0.53	0.52
S4	0.68	0.61	0.57	0.56	0.45	0.39
S5	0.57	0.52	0.52	0.40	0.37	0.31
S6	0.72	0.80	0.62	0.71	0.55	0.55
Mean	0.65	0.64	0.52	0.52	0.46	0.43
SD	0.05	0.08	0.07	0.10	0.06	0.08

DISCUSSION

The inability of the experimental intervention to produce an increase in BMD over a seven-month period of dynamic exercise training led to questions about long-term participation in a similar exercise program. Subsequent to our findings with the experimental subjects, we decided to obtain BMD measurements on three other men with SCI who had been involved in other programs in our laboratories.

Three men with SCI (two paraplegics, aged 31 and 24 years, and one quadriplegic, aged 28 years) were participating in a chronic, long-term exercise research program and had been using the FES bicycle ergometry exercise modality for more than three years. Their BMD in percent norm can be found in table 4. It does not appear that training over longer periods of time increases proximal femoral BMD. There was no statistically significant difference between the BMDs of the seven-month training group and the BMDs of the three-year training group. However, without pretraining BMD measurements for the latter group, it is only possible to make a qualitative judgment as to whether the FES bicycle ergometry exercise had an impact on their BMD. The similarity between the pretraining BMD measurements of the short-term FES subjects and those of the three long-term training subjects is consistent with the hypothesis that FES bicycle ergometry training of up to three years has no effect on BMD measurements in SCI individuals. As presented in table 4, the BMD for the eighth subject (S8) is greater than the rest of the subjects. Although no obvious causal interpretation can be made for this differ-

Table 3: Bone Mineral Density (Percent Normal) in Six Quadriplegic Men Before and After Six Months of FES Bicycle Ergometry

	Femoral neck		Ward triangle		Trochanter	
	Before	After	Before	After	Before	After
S1	65.6	69.3	47.8	55.3	50.8	51.8
S2	59.2	53.7	57.3	44.0	47.0	40.1
S3	68.6	66.4	62.8	58.8	68.5	66.5
S4	72.1	64.7	63.5	62.5	58.1	51.3
S5	72.5	80.2	66.3	75.5	67.8	68.0
S6	62.1	62.6	46.9	46.3	53.8	53.4
Mean	66.65	66.15	57.43	57.07	57.67	55.13
SD	5.39	8.68	8.34	11.51	8.90	10.50

Table 4: Bone Mineral Density (Percent Normal) in Three Quadriplegic Men After Three Years of FES Bicycle Ergometry

	Femoral neck	Ward triangle	Trochanter
S7	66.4	69.4	53.5
S8	83.0	77.4	83.9
S9	48.3	42.8	44.6

ence, this subject may have been in the upper extreme for BMD in the able-bodied population distribution before his injury.

It is generally accepted that osteoporosis is an inevitable sequela of SCI. This study provided evidence that FES bicycle ergometry training did not increase BMD in the proximal femur after six months of FES bicycle ergometry training. Subsequent additional measures of the femoral BMD obtained for the long-term training subjects (ie, more than three years) indicates that this exercise modality does not reverse SCI-associated osteoporosis.

There is ample evidence that SCI, immobilization, and recumbency cause increases of calcium excretion. One of the major differences between bone resorption metabolites excreted after a traumatic SCI and those excreted in able-bodied subjects during recumbency or weightlessness is the quantitative difference in hydroxyproline excretion. This represents a breakdown of the protein bone matrix after SCI not seen in the able-bodied during recumbency or weightlessness,[7,8] in addition to the decalcification observed in both conditions. There is evidence that some weight-bearing activities may decrease the levels of metabolites indicative of bone resorption,[11,12] although the studies failed to consider that excretory rates of calcium tend to return toward normal values without any intervention.[2] However, it does not necessarily follow that weight-bearing activities will reverse the actual mineral deficit left in the bone once osteopenia has been established. The results of the present study may simply reflect the accuracy of a statement contained in a Health Technology Assessment report published by the US Department of Health and Human Services. It was stated that "at present there is no reliable method to treat or reverse osteoporosis after it has been diagnosed."[18]

The approach toward the problem of SCI-associated osteoporosis should focus on the physiologic determinants of the development of osteoporosis. As Sir Ludwig suggested many years ago,[13] and more recent research has indicated,[6,19,20] bone blood flow may play a major role in producing an intraosseous environment which enhances bone resorption. Further investigation of this phenomenon may lead to therapies which, if introduced early enough, could prevent the development of SCI-associated osteoporosis.

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