Evaluation of Bone Mineral Density in Patients With Spinal Cord Injury

Kurtulus Kaya, MD; Canan Aybay, MD; Sumru Ozel, MD; Nilufer Kutay; Ordu Gokkaya, MD

Ankara Physical Medicine and Rehabilitation Education and Research Hospital, Sıhhiye, Ankara, Turkey

Received December 15, 2004; accepted August 22, 2005

Abstract

Background/Objective: This study was performed to evaluate the bone mineral density (BMD) values in patients with spinal cord injury (SCI) and determine the effects of the level, severity, and duration of the neurological lesion and spasticity on BMD values.

Methods: A total of 75 patients with traumatic SCI and a healthy control group of 39 people were included in the study. The BMD values of the lumbar spine and 4 different regions of the hip (femoral neck, Ward's triangle, trochanter, and femoral shaft) of all cases were measured using dual energy x-ray absorptiometry. The biochemical markers were also analyzed.

Results: The BMD values in all measured regions were found to be decreased in patients compared with that of controls. The level and severity of the lesion and the spasticity did not significantly affect BMD values in the regions analyzed. The BMD values of the hip decreased as the duration of SCI increased. The levels of plasma phosphorus and alkaline phosphatase, calcium in 24-hour urine samples, and the calcium/creatinine ratio in spot urines were found to be significantly higher in the patient group.

Conclusion: All patients with SCI had lower BMD values than controls. The level and severity of SCI and spasticity did not significantly affect BMD values. The BMD values of the hip decreased as the duration of SCI increased.

J Spinal Cord Med. 2006;29:396–401

Key Words: Spinal cord injuries; Osteoporosis; Bone mineral density; Dual energy x-ray absorptiometry; Tetraplegia; Paraplegia

INTRODUCTION

It is well known that spinal cord injury (SCI) is accompanied by the loss of bone mass caused by accelerated bone remodeling, with bone resorption exceeding bone formation. This situation causes a net bone loss and ultimately leads to osteoporosis (1). Osteoporosis in patients with SCI is usually observed in the paralyzed limbs. The most affected areas are the trabecular metaphyseal–epiphyseal sections of the distal femur and proximal tibia (2). Development of severe osteoporosis in the paralyzed part of the body is accompanied by the loss of biomechanical strength. In addition, the biosynthesis of a structurally modified matrix is unable to sustain normal mechanical stress. Therefore, the risk of fracture is dramatically increased (1,2). Although the exact sequence of metabolic events

resulting in bone loss is still not fully understood, some authors reported that vascular changes caused by the lesions of the autonomic nervous system are important in the development of osteoporosis in SCI and that immobilization is only a minor factor (2–5).

The purpose of this study was to evaluate bone mineral density (BMD) values in patients with SCI and to determine the effects of the level, severity, and duration of the neurological lesion and spasticity on BMD values.

METHODS

This study was carried out from April 2001 through January 2002 at the Ankara Physical Medicine and Rehabilitation Education and Research Hospital (Ankara, Turkey). A total of 75 patients with traumatic SCI and 39 able-bodied controls were included in the study. All Turkish subjects were informed about the procedures, and all gave informed consent. Exclusion criteria included the following: (a) use of drugs that could affect bone metabolism; (b) diseases that could affect bone metabolism; (c) internal fixation at the hip (SCI group); (d)

Please address correspondence to Canan Aybay, MD, Mektep Sokak, No:18/8, 06600, Kurtulus, Ankara, Turkey; phone: 90.312.3103230, ext. 428; fax: 90.312.3104242 (e-mail: cananaybay@yahoo.com).

Table 1. Comparison of the BMD Values of the Patient and Control Groups According to the Measurement Sections

Measurement Sections	BMD Values of the Patients (g/cm ²)	BMD Values of the Control Group (g/cm ²)	<i>t</i> Values	<i>P</i> Values
L2–L4 lumbar spine	1.121 ± 0.1674	1.221 ± 0.1626	–2.576	0.012
Femoral neck	0.928 ± 0.2112	1.029 ± 0.1414	–2.677	0.009
Wards triangle	0.837 ± 0.2176	0.920 ± 0.1734	–2.063	0.041
Trochanter	0.773 ± 0.1792	0.859 ± 0.1368	–2.637	0.010
Femoral shaft	1.067 ± 0.2132	1.1822 ± 0.1958	–2.779	0.006

Values are means ± SD.

postmenopausal women; and (e) SCI of nontraumatic etiology. Smoking habits and alcohol, tea, and coffee consumption were also recorded because these can affect BMD values.

The neurological examination, the evaluation of BMD, and the laboratory tests specific for osteoporosis were done simultaneously during the study. The neurological examination was performed according to the American Spinal Injury Association (ASIA) Impairment Scale (6). The patients were divided into motor complete (ASIA A and B) and motor incomplete (ASIA C and D) groups (2). They were further divided into acute (0–3 months), subacute (4–6 months), and chronic (7–24 months) injury groups according to the time period after the injury (7). Muscle tone was evaluated using the Modified Ashworth Scale (8), and the patients were classified into 3 groups as flaccid, normal (Ashworth 0), and spastic (Ashworth 1, 1+, 2, 3, and 4).

The BMD measurements of the patient and control groups were determined with single-section method using dual energy x-ray absorptiometry (DEXA; Lunar, DPX-IQ, Madison, WI). The measurement was performed on the L2 to L4 lumbar spine and the hip by means of a posteroanterior projection while the patient was in the supine position. The parts of the hip including the femoral neck, Ward's triangle, trochanter, and femoral shaft were evaluated. The 41 subjects with instrumentation in their lumbar spine in the patient group had BMD measurements only of the hip. The lumbar spine BMD measurements were obtained from all 22 patients with tetraplegia and 12 of 53 patients with paraplegia.

In the patient and control groups, BMD measurements (g/cm²) were calculated. The effects of the level (paraplegic and tetraplegic) and the severity (motor complete and motor incomplete) of the spinal cord lesion and muscle tone on BMD values were evaluated. The effect of ambulation on BMD values could not be studied because the size of each group was too small to find this effect. However, the relationship between the duration of SCI and BMD values and the duration of SCI and the laboratory parameters were studied. Calcium, phosphorus, and alkaline phosphatase (ALP) levels, thyroid function tests (TFT), parathyroid hormone (PTH) and

calcitonin levels in plasma, calcium excretion level in 24-hour urine samples, and the calcium/creatinine ratio for the spot urine samples were measured. PTH was measured using immunometric assay (IMMULITE 1000 systems, DPC, Los Angeles, CA). The laboratory values of the patients were also compared with those of controls. In the statistical analysis, χ^2 test, Student *t* test, Mann-Whitney *U* test, one-way variance analysis (one-way ANOVA), 2 × 2 variance analysis, and least significant differences analysis were used. *P* < 0.05 was regarded as statistically significant.

RESULTS

The patient group consisted of 54 men (72%) and 21 women (28%) with SCI. The control group consisted of 26 men (66.7%) and 13 women (33.3%). The female–male ratio was similar in both groups (*P* = 0.175). The mean age of the patients was 33.01 ± 9.28 years (range: 19–60 years), and the mean age of the controls was 35.69 ± 11.11 years (range: 20–60 years). There was no significant difference between the 2 groups in terms of age, smoking habits, and tea, coffee, and alcohol consumption (*P* = 0.557, *P* = 0.885, *P* = 0.414, *P* = 0.078, and *P* = 0.865, respectively).

The BMD values of the patient and control groups are shown in Table 1. The BMD values of the patient group were significantly lower than those of the control group in all regions. Of 75 patients with SCI, 43 (57.3%) had complete paraplegia, 10 (13.3%) had incomplete paraplegia, 11 (14.7%) had complete tetraplegia, and 11 (14.7%) had incomplete tetraplegia. When the time period after the injury was evaluated, 33 (44%) patients were in the acute, 10 (13.3%) patients were in the subacute, and 32 (42.7%) patients were in the chronic period. In the sense of age, sex, smoking habits, and tea, coffee, and alcohol consumption, no significant difference was observed among the following subgroups: (a) motor complete and motor incomplete; (b) paraplegia and tetraplegia; and (c) acute, subacute, and chronic groups. The duration of SCI did not show any significant difference between the motor complete and the motor incomplete or paraplegic and tetraplegic groups (*P* > 0.05).

Table 2. Comparison of the Patient and Control Groups in Terms of Laboratory Parameters

Laboratory Parameters	SCI	Controls	<i>t</i> Values	<i>P</i> Values
Plasma parathormone level (pmol/L)	2.23 ± 1.27	2.19 ± 1.46	0.141	0.888
Plasma calcitonin level (mg/dL)	7.84 ± 3.15	8.31 ± 5.46	−0.557	0.579
Plasma fT3 level (pg/mL)	2.47 ± 0.61	2.55 ± 0.33	−0.698	0.487
Plasma fT4 level (ng/mL)	1.20 ± 0.23	1.22 ± 0.24	−0.312	0.750
Plasma TSH level (μIU/mL)	1.45 ± 1.04	1.40 ± 0.88	0.259	0.796
Plasma calcium level (mg/dL)	9.60 ± 0.56	9.60 ± 0.49	−0.013	0.989
Plasma phosphorus level (mg/dL)	4.38 ± 0.70	3.73 ± 0.54	5.009	0.000
Plasma alkaline phosphatase level (U/L)	100.05 ± 36.98	71.10 ± 23.10	4.404	0.000
Calcium excretion in 24 hours urine (mg)	238.81 ± 153.61	174.89 ± 103.22	2.312	0.023
Calcium/creatinine in spot urine	0.31 ± 0.30	0.13 ± 0.18	3.365	0.001

Values are means ± SD.

When the effect of the lesion level (paraplegic and tetraplegic) on BMD values was studied, there was no significant difference between the paraplegic and tetraplegic groups in terms of BMD values of the lumbar spine (L2–L4), femoral neck, Ward's triangle, trochanter, and femoral shaft ($P = 0.313$, $P = 0.608$, $P = 0.456$, $P = 0.381$, and $P = 0.915$, respectively). Similarly, no significant difference was observed between the motor complete and motor incomplete groups ($P = 0.822$, $P = 0.940$, $P = 0.895$, $P = 0.434$, and $P = 0.352$, respectively). There was also no combined effect of the level and severity of the lesion on BMD values ($P = 0.890$, $P = 0.423$, $P = 0.697$, $P = 0.982$, and $P = 0.400$, respectively). The BMD values of the same regions did not differ significantly among the flaccid, normal, and spastic patient groups ($P = 0.954$, $P = 0.536$, $P = 0.184$, $P = 0.612$, and $P = 0.951$, respectively).

Plasma PTH, calcitonin, free T3 (fT3), free T4 (fT4), thyroid stimulating hormone (TSH), and plasma calcium levels did not differ significantly between the patient group and controls. However, the plasma phosphorus and ALP levels, calcium excretion in 24-hour urine, and calcium/creatinine ratio in spot urine were significantly higher in the patient group (Table 2).

Although there were no differences in the L2 to L4 BMD values in the patient group related to the duration of SCI (acute, subacute, and chronic; Table 3), decreases

of 9.5% in the acute group and 10% in the subacute group were observed compared with controls. Although there was an increase of 7.1% in the chronic group compared with the controls, these differences were not significant. However, significant differences were observed regarding BMD values of the proximal femur depending on the duration of SCI. Comparisons between the acute and subacute group or the subacute and chronic group did not differ for BMD values of all proximal femurs ($P > 0.05$). However, a prominent difference in the BMD values of the proximal femur was observed between the acute and chronic period ($P < 0.05$; Table 3). In addition, a weak correlation was observed between the BMD values of the proximal femur and the duration of SCI (for the femoral neck; $r = -0.40$, $P = 0.000$).

We did not observed any statistically significant relationship with plasma PTH level, calcitonin, fT3, fT4, TSH, calcium, or ALP to duration of SCI ($P = 0.056$, $P = 0.182$, $P = 0.203$, $P = 0.774$, $P = 0.129$, $P = 0.377$, and $P = 0.223$, respectively). However, plasma phosphorus level, calcium excretion in 24-hour urine, and the calcium/creatinine ratio in spot urine were related to the duration of SCI. The plasma phosphorus levels differed between acute and subacute patients and the acute and chronic patients ($P = 0.001$ and $P = 0.001$, respectively) but were almost similar between the subacute and chronic patients

Table 3. Comparison of the BMD Values of the Patients With SCI by Duration of SCI

Duration of SCI	L2–L4 Lumbar Spine (g/cm ²)	Femoral Neck (g/cm ²)	Ward's Triangle (g/cm ²)	Trochanter (g/cm ²)	Femoral Shaft (g/cm ²)
0–3 months	1.105 ± 0.1494	1.011 ± 0.1543	0.905 ± 0.1668	0.858 ± 0.1156	1.135 ± 0.1716
4–6 months	1.097 ± 0.9025	0.914 ± 0.1918	0.840 ± 0.2155	0.760 ± 0.1810	1.097 ± 0.1916
7–24 months	1.139 ± 0.1948	0.846 ± 0.2378	0.766 ± 0.2461	0.698 ± 0.1957	0.984 ± 0.2367
F value	0.186	5.643	3.586	8.811	4.395
P value	0.831	0.005	0.033	0.000	0.016

($P = 0.831$). A significant increase in the calcium level in 24-hour urine samples was observed in acute patients compared with normal individuals or subacute ($P = 0.01$) or chronic patients ($P = 0.000$). However, there was no difference when the comparison was made between the subacute and chronic patients ($P = 0.438$). Similar results were observed for the calcium/creatinine ratio in spot urine. It was concluded that these increases in parameters, ie, the plasma phosphorus level, the calcium excretion in 24-hour urine, and the calcium/creatinine ratio in spot urine, originated from the acute period ($P = 0.001$, $P = 0.000$, and $P = 0.002$, respectively).

The calcium excretion in 24-hour urine and the calcium/creatinine ratio in spot urine did not differ significantly between paraplegia and tetraplegia ($P = 0.698$ and $P = 0.893$, respectively). However, when the calcium excretions in 24-hour urine samples were compared for patients with complete and incomplete acute plegia, the calcium excretion was significantly higher in patients with complete acute plegia ($P = 0.023$).

DISCUSSION

It was shown that bone mass decreases rapidly after SCI, and there is a balance between bone formation and resorption within the 16th month (9). Sorensen et al (10) proved that bone loss continues in the femoral neck and the metaphysis of the proximal tibia in the 3 years after trauma. In our study, for patients with SCI, the BMD values at the lumbar spine (L2–L4) and hip were significantly lower than those of the control group. There was a slight reduction in the L2 to L4 BMD values of patients with acute or subacute SCI compared with controls. The limited increase in lumbar BMD values of the chronic group compared with the controls might be related to wheelchair use, because the sitting position enables the loading of truncal weight on the lumbar spine. The decrease in the BMD values of the lumbar spine in the first 6 months can be explained by the negative effects of long bed rest or a delayed rehabilitation program. Therefore, the stimulant effect of the truncal weight on the lumbar spine diminishes.

In our study, the BMD values of all proximal femurs were significantly different when the acute and the chronic groups were compared. When the femoral BMD values of the patients for the acute group were compared with the control group, there was a 1% decrease in the femoral neck and 3.9% decrease in the femoral shaft. These decreases reached 17.7% and 16.7% in the chronic period, respectively. The relationship between the duration of SCI and the femoral BMD values was statistically significant. It was proposed that the overall bone loss occurring during the first months after onset was certainly overestimated by previous studies, mainly because of the large imprecision of the dual photon absorptiometry technique used (11). The slight decrease in the femoral BMD values during the acute period observed in our study supported this suggestion.

There have been a few studies reporting a decrease in the BMD values of the bones underlying the lesion after SCI. In the study by Dauty et al (2), performed on 11 patients with tetraplegia and 20 men with paraplegia having had SCI more than 1 year, the bone mineral losses in the lumbar spine, the femoral neck, and the trochanter were reported as 11%, 30%, and 39%, respectively. They found that the femoral metaphyseal–epiphyseal sections and the proximal tibia were mostly affected. When the BMD values of complete and incomplete lesions were compared, there was not a statistically significant difference. When the patients with paraplegia and tetraplegia were compared, the BMD values did not show a significant difference except for the trochanter. Dauty et al (2) declared that there was no correlation between the daily sitting period and lumbar BMD values or between the daily passive verticalization period and the lower extremity BMD values. In addition, they showed that there was no relation between the lower extremity BMD values and the use of long leg braces. Hence, they suggested that biomechanical stress had no effect on BMD values, and the neurological state played a major role on bone loss (2).

Similarly, we could not show a significant difference in the BMD values in terms of the severity and level of the neurological lesion. Although the BMD values of the patients with incomplete SCI showed a tendency to be higher than the patients with complete SCI, the difference was not statistically significant. Chantraine et al (5) supported this finding by proposing the theory that opening of intravenous bone shunts leads to venous and capillary vascular stasis and to the deafferentation of the sympathetic nerve system. Therefore, the vascular hyperplasia, which is a result of the opening of the arteriovenous shunts, leads to a reduction in bone nutrition, an increase in local pressure, venous stasis, and the transformation of the mesenchymal cells into osteoclastic cells. This theory might explain the intense bone loss of the vascular-rich metaphyseal–epiphyseal sections of the long bones. Chantraine (3) believed that vascular changes depending on the lesions of the autonomic nervous system are more important than immobilization in the development of SCI-induced osteoporosis. We believe that the sample size needs to be larger to determine the changes in the BMD values depending on the level of ambulation. The hospitalization period, the duration of SCI, and the daily ambulatory period of the ambulatory patients were varied. Thus, we were not able to analyze the relationship between the level of ambulation and BMD values. However, we could not determine any significant difference between the BMD values for patients with motor incomplete and complete SCI.

As discussed by many authors, whereas the BMD value of the lumbar spine is normal or minimally decreased, a significant decrease occurs in the proximal femur after SCI. It was also reported that BMD values of

all proximal femurs progressively decreased as the duration of SCI increased (10,12–14). In our study, we found a prominent bone loss in BMD values of all proximal femurs of the patients in the chronic period compared with controls.

In our study, no difference was observed in the lumbar and femoral BMD values related to muscle tone. The data reported by Ragnarsson et al (15) support the results of our study; they found that spasticity had no protective effect on the BMD values of the lower extremities and that there was no difference in fracture incidence of the lower extremities between spastic and flaccid paralysis. In another study performed with 14 male patients with chronic SCI, the relationship between BMD values of the femoral neck and Ashworth spasticity scale was found to be weak and had no statistical significance (16). We also observed that the femoral BMD values were found to be higher in the spastic group, but the difference was not prominent.

The plasma calcium levels of the patient and control groups were similar to each other. However, the calcium excretion in 24-hour urine samples and the calcium/creatinine ratio in spot urines were found to be significantly higher in the patient group compared with the control group. In the acute period, there might be an increase in bone resorption, which might explain this increase. The calcium released from the bone tissue is excreted through the urinary tract; there is no rise in the plasma levels in normal renal function. The suppressed plasma PTH levels might be related to the increased bone resorption followed by increased plasma phosphorus level. In some studies, hypercalciuria and suppressed PTH levels were found, whereas plasma calcium levels were normal in patients with SCI during the acute period (17,18).

In our study, plasma phosphorus levels were significantly higher in the patient group. This increase can be explained by the loss of phosphorus from bones and muscle tissue (2). In the acute period, we found that the suppression of plasma PTH levels nearly achieved statistical significance. We hypothesized that the significantly increased phosphorus levels were related to this situation. We found that plasma ALP levels were significantly higher in the patient group. Heterotopic ossification was ruled out in patients with high ALP levels. In the acute period, calcium in 24-hour urines and calcium/creatinine ratio in spot urines was significantly higher compared with other periods, as well as plasma ALP levels, which we consider to be representative of bone formation. We conclude that bone formation is trying to compensate for bone loss during the acute period. This finding explains the minimal bone loss in the femoral region (1% in the femoral neck) determined by DEXA in the acute period. The study by Maimoun et al (17), performed on 7 patients with acute and complete SCI, supported this finding. In that study, they concluded that it would not be possible to determine the BMD

changes in the early period of SCI by using DEXA. However, the bone resorption and formation markers in the acute period can be used to determine the risk of osteoporosis for patients in the early period after SCI.

Immobilization is not the only reason for the osteoporosis seen after SCI. The immobilization, which is a result of neurological diseases and its complications, leads to a more severe bone loss compared with immobilization as a result of bed rest, which is not associated with neurological diseases. It was reported that the urinary hydroxyproline excretion of patients with SCI was 3 times higher than in normal individuals after a period of bed rest (4). It is not certain that any improving strategy applicable after SCI can preserve bone mass. However, it is commonly believed that remobilization does not repair bone loss in the first 6 months after immobilization. In another study, there was no improvement in bone mass in the first year after injury, even in patients who achieved close to normal mobility (19). Furthermore, the lower BMD values of the Frankel D ambulatory patients compared with the patients with prolonged periods of bed rest led to the claim of some authors that some factors affecting the skeletal system are independent from mechanical loading (16). The BMD values of our patients with incomplete SCI were not significantly higher than the BMD values of patients with complete SCI. The BMD values of our patients in the acute period did not decrease significantly in the proximal femur and femoral shaft with the exception of lumbar spine. In the subacute period, whereas the loss of the lumbar spine remained nearly the same, in the proximal femur and femoral shaft, both of which are rich in cortical bone, the rate of the bone loss was close to the rate of the loss in the lumbar spine. In the chronic period, although the BMD values of the lumbar spine increased, we showed that the bone loss increased in all proximal femurs. Thus, we share the same opinion with Szollar (20), who claimed that control BMD measurements against bone loss should be started within 1 year after the injury, and if the BMD values were close to the osteoporosis margin, treatment should be started in the first year. Zehnder et al (21) reported that, in men with paraplegia, SCI bone loss was stopped at all measured cortical and trabecular infralesional sites over 24 months with alendronate 10 mg daily.

CONCLUSION

Our results showed that, compared with able-bodied individuals, patients with SCI had lower BMD values in all areas studied. The level and severity of the lesion and spasticity did not significantly affect BMD values of all areas in patients with SCI. The BMD values of all proximal femurs decreased as the duration of SCI increased. According to our results, osteoporosis should be investigated and followed up by means of BMD measurements. Biochemical markers should be done in

individuals with SCI as early as possible, regardless of lesion level and severity.

REFERENCES

1. Szollar SM, Martin EME, Sartoris DJ, Parthemore JG, Deftos LJ. Bone mineral density and indexes of bone metabolism in spinal cord injury. *Am J Phys Med Rehabil*. 1998;77:28–35.
2. Dauty M, Verbe BP, Maugars Y, Dubois C, Mathe JF. Supralesional and sublesional bone mineral density in spinal cord-injured patients. *Bone*. 2000;27:305–309.
3. Chantaine A. Actual concept of osteoporosis in paraplegia. *Paraplegia*. 1978–1979;16:51–58.
4. Chantaine A, Nusgens B, Lapiere M. Bone remodelling during the development of osteoporosis in paraplegia. *Calcif Tissue Int*. 1986;38:323–327.
5. Chantaine A, Van Ouwenaller C, Hachen HJ, Schinas P. Intramedullary pressure and intra-osseous phlebography in paraplegia. *Paraplegia*. 1979;17:391–397.
6. Frost FS. Spinal cord injury medicine. In: Braddom RL, ed. *Physical Medicine and Rehabilitation*. Philadelphia, PA: WB Saunders Co; 2000;1230–1282.
7. Naftchi NE, Viau AT, Sell GH, Lowman EW. Mineral metabolism in spinal cord injury. *Arch Phys Med Rehabil*. 1980;61:139–142.
8. Bohannon RW, Smith MB. Interrater reliability on a modified Ashworth scale of muscle spasticity. *Phys Therap*. 1987;67:206–207.
9. Garland DE, Steward CA, Adkins RH, et al. Osteoporosis after spinal cord injury. *J Orthop Rel Res*. 1992;10:371–378.
10. Sorensen FB, Bohr H, Schaadt O. Bone mineral content of the lumbar spine and lower extremities years after spinal cord lesion. *Paraplegia*. 1988;26:293–301.
11. Uebelhart D, Demiaux-Domenech B, Roth M, Chantaine A. Bone metabolism in spinal cord injured individuals and in others who have prolonged immobilization. A review. *Paraplegia*. 1995;33:669–673.
12. Sabo D, Blaich S, Wenz W, Hohmann M, Loew M. Osteoporosis in patient with paralysis after spinal cord injury. *Arch Orthop Trauma Surg*. 2001;121:75–78.
13. Sorensen FB, Bohr HH, Schaadt OP. Longitudinal study of bone mineral content in the lumbar spine, the forearm and the lower extremities after spinal cord injury. *Eur J Clin Invest*. 1990;20:330–335.
14. Kiratli BJ, Smith AE, Nauenberg T, Kallfelz CF, Perkash I. Bone mineral and geometric changes through the femur with immobilization due to spinal cord injury. *J Rehabil Res Dev*. 2000;37:225–233.
15. Ragnarsson KT, Sell GH. Lower extremity fractures after spinal cord injury: a retrospective study. *Arch Phys Med Rehabil*. 1981;62:418–423.
16. Leslie WD, Nance PW. Dissociated hip and spine demineralization: a specific finding in spinal cord injury. *Arch Phys Med Rehabil*. 1993;74:960–964.
17. Maimoun L, Couret I, Micallef JP, et al. Use of bone biochemical markers with dual-energy x-ray absorptiometry for early determination of bone loss in persons with spinal cord injury. *Metabolism*. 2002;51:958–963.
18. Pietschmann P, Pils P, Woloszczuk W, Maerk R, Lessan D, Stipicic J. Increased serum osteocalcin levels in patients with paraplegia. *Paraplegia*. 1992;30:204–209.
19. Wilmet E, Ismail AA, Heilporn A, Welraeds D, Bergmann P. Longitudinal study of the bone mineral content and of soft tissue composition after spinal cord section. *Paraplegia*. 1995;33:674–677.
20. Szollar SM. Osteoporosis in men with spinal cord injuries. *West J Med*. 1997;166:270.
21. Zehnder Y, Risi S, Michel D, et al. Prevention of bone loss in paraplegics over 2 years with alendronate. *J Bone Miner Res*. 2004;19:1067–1074.