Underestimation of Bone Loss of the Spine With Posterior-Anterior Dual-Energy X-Ray Absorptiometry in Patients With Spinal Cord Injury

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Abstract

Background: Bone mineral density (BMD) of the lumbar spine (L-spine) has been reported to be normal by routine posterior-anterior (PA) bone density imaging in patients with chronic spinal cord injury (SCI).

Objective: To determine BMD of the L-spine by PA and lateral (LAT) dual-energy radiographic absorptiometry (DXA) in patients with chronic SCI.

Design: Prospective study.

Setting: Veterans Affairs Medical Center and a private rehabilitation facility.

Methods: Measurements of the PA and LAT L-spine and hip were performed in 15 patients with SCI: 9 with tetraplegia and 6 with paraplegia. The DXA (GE Lunar Advance DXA) images were obtained using standard software. Results are reported as mean $\pm$ SD.

Results: The mean age was 35 ± 15 years (range = 20–62 years), and the duration of injury was 57 ± 74 months (range = 3–240 months). T- and Z-scores were lower for the LAT L-spine than those for PA L-spine (T-scores L2: -0.7 ± 1.2 vs 0.0 ± 1.4 , $P < 0.01$; L3: -0.9 ± 1.6 vs 0.3 ± 1.3 , $P < 0.002$; L2-L3: -0.8 ± 1.3 vs 0.2 ± 1.3 , $P < 0.001$; Z-scores L2: -0.3 ± 1.1 vs 0.2 ± 1.2 , $P < 0.05$; L3: -0.6 ± 1.3 vs 0.5 ± 1.3 , $P < 0.01$; L2-L3: -0.4 ± 1.1 vs 0.4 ± 1.2 , $P < 0.005$). The T- and Z-scores for the total hip (-1.1 ± 1.0 and -1.0 ± 1.0 , respectively) and L2-L3 LAT L-spine demonstrated remarkable similarity, whereas the L2-L3 PA L-spine scores were not reduced. Bone mineral density of the LAT L-spine, but not the PA L-spine, was significantly reduced with increasing duration of injury.

Conclusions: Individuals with SCI may have bone loss of the L-spine that is evident on LAT DXA that may be misdiagnosed by PA DXA, underestimating the potential risk of fracture.

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

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INTRODUCTION

Osteoporosis is a predictable occurrence of the long bones below the level of injury in individuals with chronic spinal cord injury (SCI) that predisposes to fracture (1–6). Contrary to the extremities and pelvis, several cross-sectional studies have found that the vertebral column does not appear to lose bone mass after paralysis but, rather, tends to gain bone mass with age and/or longer duration of injury (DOI) (1,7–11). However, recent reports have challenged the notion that the vertebral bodies are spared loss of bone mineral density (BMD)

Table 1. Demographic Information

	Mean $\pm$ SD	Minimum	Maximum
No. of patients	15		
Age (y)	35 $\pm$ 15	20	62
Height (cm)	174 $\pm$ 11	152	188
Weight (kg)	75 $\pm$ 16	48.6	107.6
Body mass index (kg/m ²)	25.0 $\pm$ 5.4	17.7	40.5

after paralysis (12–14). These more recent studies have suggested that the absence of osteoporosis of the spine is a spurious finding of standard posterior-anterior (PA) dual-energy radiographic absorptiometry (DXA) (12,13). PA L-spine DXA measurement has been widely used to determine BMD of the hip and lumbar spine (L-spine) in the general population because of its low level of radiation exposure, ease of performance, and reproducibility of results, permitting rapid and reliable diagnosis. A potential drawback of the PA determination of L-spine BMD is that the field of measurement includes extraneous calcification, which usually consists of osteophyte formation. Extravertebral calcification in the general population, which increases with advancing age, may obscure the diagnosis of osteoporosis (15–17). In patients with SCI who are known to have neuropathic calcification, PA DXA of the L-spine may lead to overestimation of bone mass and the clinical misinterpretation of results, whereas DXA imaging of the lateral (LAT) L-spine may, in part, reduce this artifact of imaging. In this study, we compared the T- and Z-scores from DXA images of the PA and LAT L-spine in patients with SCI because of our hypothesis that the PA projection would overestimate BMD of the L-spine due to extraneous calcification.

METHODS

Fifteen patients with SCI (12 men, 3 women) were recruited for study (Tables 1 and 2). There were 6 with paraplegia and 9 with tetraplegia. All were nonambulatory, classified according to the ASIA Classification A to C; 7 had motor complete SCI and 8 had motor incomplete SCI (Tables 1 and 2). To test effects of DOI after the acute phase (eg, most of the rapid bone loss will have occurred within the initial 18 months after injury), patients were divided into those with a DOI <18 months after injury and those with a DOI $\geq$ 18 months. Patients with known bone disease (eg, heterotopic ossification, previous fracture), predisposing conditions for bone disease, or surgical hardware of the L-spine or hip regions were excluded from study participation. Patients were recruited from the Kessler Institute of Rehabilitation, West Orange, New Jersey, and the SCI Service of the James J. Peters Veterans Affairs Medical Center, Bronx, NY. Institutional Review Board approval was obtained from the Veterans Affairs Medical Center and the Kessler

Foundation Research Center. Informed consent was obtained from patients prior to the study.

PA and LAT DXA images of the second lumbar (L2) and third lumbar (L3) vertebrae, as well as the combined vertebral segments (L2-L3), of the L-spine were acquired (GE Lunar Prodigy Advance DXA, Milwaukee, WI) with the region of interest isolated for quantification of BMD and generation of the T- and Z-scores by the combined GE Lunar/NHANES III normative database (Lunar Prodigy, version 12.1, Madison, WI). Total hip and femoral neck images were also obtained. Day-to-day DXA variation determined over a 12-month period using a PA spine phantom (aluminum spine encased in acrylic) scanned 38 consecutive times was <1% (coefficient of variation = 0.06).

Statistical Analyses

The results are expressed as mean $\pm$ SD. A paired *t*-test was used to determine significance of differences between the PA L-spine and LAT L-spine for the T- and Z-scores and BMD values. A one-factor repeated measure ANOVA with a Fisher protected least squares difference posthoc test was used to determine the significant differences between the PA L-spine, LAT L-spine, total hip, and femoral neck for the T- and Z-scores. Pearson correlation coefficients were used to determine associations between DOI and the BMD and T- and Z-scores for each of the variables. Simple regression models were used to report the relationship between DOI and the PA or LAT L-spine values with those of the total hip BMD and T-scores.

RESULTS

There were no significant differences for paraplegia compared with tetraplegia for values of the L-spine, permitting results to be combined and analyzed as a single group of all participants (Table 3). Comparison of the LAT with the PA L-spine for L2, L3, and L2-L3 revealed that the T- and Z-scores were generally lower at each vertebral level for the LAT than those for the PA L-spine (Table 4 and Figure 1). The T- and Z-scores for the LAT L-spine (L2, L3, and L2-L3), total hip, and femoral neck were below-average values (Figure 1). T- and Z-score comparisons of the LAT L-spine with total hip and femoral neck were not significantly different, except for the L2 LAT Z-score with that of the total hip (-0.26 ± 1.10 vs -0.97 ± 1.0 , $P < 0.05$) (Figure 1). In contrast, the mean T- and Z-scores for PA L-spine (L2, L3, and L2-L3) were significantly different from those of the total hip (Figure 1).

No patient with a negative T- or Z-score of the PA L-spine had a positive LAT L-spine score, but 4 who had a negative T- or Z-score on LAT L-spine had positive PA L-spine scores. Of note, on PA L-spine (L2 or L3), only 3 patients were noted to have low bone mass by T-score criteria (eg, -1.0 to -2.5); however, on LAT L-spine of these same 3 patients, 1 had low bone mass and 2 met

Table 2. Neurologic and Demographic Characteristics by Patient

Patient No.	LOL	Motor COL	DOI (Months)	Gender	Ethnicity	Current Smoker
1	T6	Incomplete	47	Male	Caucasian	No
2	C4	Incomplete	240	Female	Caucasian	No
3	T9	Incomplete	113	Female	Caucasian	Yes
4	C2	Incomplete	5	Male	Caucasian	No
5	C6	Complete	27	Male	Hispanic	No
6	C8	Incomplete	117	Male	Caucasian	No
7	T4	Complete	6	Male	Caucasian	No
8	C6	Complete	16	Male	Caucasian	Yes
9	C5	Incomplete	48	Male	Caucasian	No
10	T4	Complete	20	Male	Caucasian	No
11	C5	Complete	21	Male	Caucasian	No
12	T7	Complete	3	Male	Caucasian	No
13	T7	Incomplete	3	Male	Caucasian	Yes
14	C6	Complete	5	Male	Caucasian	No
15	C1	Incomplete	190	Female	Caucasian	No
Mean $\pm$ SD			57.4 $\pm$ 71.7			

LOL, level of spinal cord lesion; T, thoracic; C, cervical; motor COL, motor complete spinal cord lesion; and DOI, duration of injury.

the criteria for osteoporosis (<-2.5). T-scores on LAT L-spine imaging of L2 or L3 revealed that 4 patients had osteoporosis and 4 had low bone mass, or 8 of 15 patients had evidence of significant vertebral bone depletion, whereas only 3 would have been identified to have low bone mass by T-scores of the PA L-spine. Of the 3 with low bone mass on the PA spine, 2 were men and 1, a woman; on LAT L-spine, 3 men and 2 women had low bone mass, and 2 men and 2 women had osteoporosis. Thus, of the group with either low bone mass or osteoporosis on LAT L-spine, 5 were men and 4 women. Five of the 12 men had motor incomplete lesions and 2 of these had the greatest bone loss (T-scores = -2.4 to -2.9); both women with osteoporosis had incomplete motor injuries with DOIs of 113 and 240 months (Table 2).

In all patients ($N = 15$), DOI was significantly inversely related to BMD of the L3 LAT spine ($R = -0.60$, $P = 0.01$), L2-L3 ($R = -0.57$, $P < 0.05$), total hip ($R = -0.61$, $P = 0.01$), and femoral neck ($R = -0.61$, $P = 0.01$). Duration of injury tended to be inversely related to BMD of the L2 LAT spine ($R = -0.42$, $P = 0.12$) (Table 5). In the subset of 9 patients with a DOI ≥ 18 months, the DOI was found to be negatively related to both the BMD and T-scores of the LAT L-spine, total hip, and femoral neck (Figure 2); it should be noted that 4 of these 9 patients had a DOI of 113 to 240 months.

DISCUSSION

This study demonstrated that T- and Z-scores of the LAT L-spine predictably demonstrated bone loss, whereas PA L-spine scores appeared to be less reliable indicators of vertebral body bone mass. Generally, the T- and Z-scores of the LAT L-spine were similar to those of the total hip

but were significantly different from those of the PA L-spine. Furthermore, longer DOI was associated with lower BMD and T- and Z-scores of the LAT L-spine, which were correlated to those values of the total hip and femoral neck for time since injury, but no correlation was found for PA spine for these measures and DOI. A limitation of this study was the number of patients with longer DOI: 4 had a DOI >9 years, with the longest DOI being 240 months. Thus, the significantly lower T- and Z-scores and the significant loss of BMD of the total hip and L3 and L2-L3 with increasing DOI serve to confirm our notion that the LAT projection is more accurate than the PA projection for the imaging of vertebrae. The inability to reveal the significance of DOI with BMD of the L2 LAT spine may have been due to vertebral compression fracture and/or extraneous calcification that was not determined, that is, not detected in this study. To date, there have been no reports that have specifically addressed compression fractures of the L-spine in patients with SCI. Furthermore, because the fragility of the L-spine has not been studied in a systematic manner, the reduction in BMD that predisposes to fracture, as well as other potential predictors of fracture risk, in this population is also not known.

In 1988, Biering-Sorensen reported that although bone mineral content of the femoral neck and shaft and proximal tibia were significantly reduced in patients with SCI, there appeared to be preservation of bone mass of the L-spine, which was postulated to be due to maintenance of weight on the spine while seated (8). Employing PA DXA as the methodology to acquire regional BMD, Leslie et al compared 14 men with chronic SCI with 46 men with various endocrine disorders that predispose to bone loss and idiopathic

Figure 1. Column plots of T- and Z-scores for total hip, femoral neck, and posterior-anterior (PA, black) and lateral (LAT, gray) lumbar spine L2, L3, and L2-L3 vertebral levels. § T-score: total hip vs PA L2 ($P = 0.0001$), PA L3 ($P < 0.0001$), PA L2-L3 ($P = 0.0001$); ‡ T-score: femoral neck vs PA L2 ($P = 0.005$), PA L3 ($P < 0.0001$), PA L2-L3 ($P = 0.0005$); § Z-score: total hip vs PA L2 ($P = 0.0001$), PA L3 ($P < 0.0001$), PA L2-L3 ($P = 0.0001$), LAT L2 ($P < 0.01$); ‡ Z-score: femoral neck vs PA L2 ($P = 0.005$), PA L3 ($P < 0.0001$), PA L2-L3 ($P = 0.0005$).

osteoporosis (10). Although the patients with SCI had marked femoral neck bone loss, they appeared to have no evidence of L-spine loss (10).

Using PA DXA as the imaging method, women with SCI after menopause have been reported to have an increase in L-spine BMD, in striking contrast to able-bodied postmenopausal women (11). Garland et al studied regional BMD of the knee, hip, and spine in 31 women with chronic SCI compared with 17 healthy age-matched able-bodied women (11). Bone mineral density of the knee and hip in these women declined markedly and in an age-related manner in the youngest (≤ 30 years), middle (31–50 years), and oldest (> 50 years) SCI subgroups, but the spine of the SCI subgroups appeared to have an age-related increase of BMD (11). Of note, the mean BMD L-spine in the oldest SCI group was similar to that of the youngest control group. Thus, there appeared to be an apparent gain in BMD of the spine in women with SCI, even after menopause, in contrast to the expected loss (11,18). Our findings in this report and our previous work (14) raise the possibility that the normal to increased L-spine

Table 3. Bone Mineral Density and T- and Z-Scores by Level of Spinal Cord Injury

	Tetraplegia (n = 9)		Paraplegia (n = 6)	
	Mean	$\pm$ SD	Mean	$\pm$ SD
BMD (g/cm ²)				
PA spine L2	1.249	0.171	1.241	0.190
PA spine L3	1.305	0.177	1.267	0.157
PA spine L2-L3	1.279	0.170	1.256	0.163
Lat spine L2	0.750	0.192	0.713	0.134
Lat spine L3	0.707	0.248	0.748	0.216
Lat spine L2-L3	0.722	0.201	0.731	0.156
Total hip	0.890	0.179	0.977	0.136
Femoral neck	0.916	0.188	0.983	0.182
T-score				
PA spine L2	0.059	1.349	-0.033	1.542
PA spine L3	0.444	1.387	0.133	1.291
PA spine L2-L3	0.267	1.332	0.033	1.338
Lat spine L2	-0.600	1.486	-1.017	1.055
Lat spine L3	-1.133	1.648	-0.683	1.665
Lat spine L2-L3	-0.933	1.570	-0.867	1.159
Total hip	-1.389	1.156	-0.767	0.855
Femoral neck	-1.089	1.347	-0.600	1.319
Z-score				
PA spine L2	0.278	1.218	0.100	1.342
PA spine L3	0.644	1.252	0.250	1.410
PA spine L2-L3	0.467	1.208	0.200	1.270
Lat spine L2	-0.133	1.109	-0.700	1.070
Lat spine L3	-0.667	1.394	-0.400	1.322
Lat spine L2-L3	-0.400	1.172	-0.617	1.026
Total hip	-1.167	1.108	-0.667	0.903
Femoral neck	-0.789	1.268	-0.483	1.113

PA, posterior-anterior; LAT, lateral; BMD, bone mineral density; and L, lumbar vertebrae.

BMD measured by PA DXA in women with SCI reported by Garland et al may have been due to extraneous calcification.

Jaovisidha et al performed a correlation analysis of vertebral levels L1 to L4 between PA radiographs of the L-spine and DXA in 116 patients with chronic SCI (12). The dataset consisted of 463 individual vertebrae as valid for comparison, that is, vertebrae without hardware or other abnormal density (12). By DXA, elevation of BMD was observed at all lumbar levels, ranging from 15% to 20%; 49% of the vertebrae were abnormal on routine spine films. The authors concluded that the elevated DXA results for BMD were due to secondary progressive skeletal abnormalities that served to prevent the identification of significant bone loss. Lui et al studied a cohort of 64 patients with chronic SCI by quantitative computerized tomography (qCT) of the lumbar spine, and they also investigated a subgroup of 29 out of 64 by qCT and

Table 4. Bone Mineral Density and T- and Z-Scores for the Total Group

	PA Spine, N = 15		LAT Spine, N = 15		P Value
	Mean	±SD	Mean	±SD	
BMD (g/cm ²)					
L2	1.246	0.172	0.735	0.167	<0.0001
L3	1.290	0.165	0.723	0.229	<0.0001
L2-L3	1.270	0.161	0.725	0.178	<0.0001
T-score					
L2	0.0	1.4	−0.8	1.3	<0.01
L3	0.3	1.3	−1.0	1.6	<0.002
L2-L3	0.7	1.3	−0.9	1.4	<0.001
Z-score					
L2	0.2	1.2	−0.4	1.1	<0.05
L3	0.5	1.3	−0.6	1.3	<0.01
L2-L3	0.4	1.2	−0.5	1.1	<0.005

PA = posterior-anterior; LAT = lateral; BMD = bone mineral density; SD = standard deviation; g = grams; cm = centimeter; and L = lumbar vertebrae.

DXA (13). In the total group, the Z-scores derived by qCT were -2.0 ± 1.2 of historic age-matched controls; in the subgroup in which both imaging techniques were performed, the qCT Z-score was -2.4 ± 1.1 and for DXA, 1.3 ± 2.3 above the mean (13). Our group recently compared BMD of the L-spine by DXA and qCT in men with chronic SCI compared with able-bodied controls; the use of qCT permitted isolation and examination of the medullary portion of trabecular bone of the vertebral body, rather than a reliance on the PA projection by DXA that captured the posterior cortical bone and potentially associated pathologic bony and vascular structures (14). A proportion of men with chronic SCI, especially those with higher cord lesions, had significant osteoporosis of the L-spine; an association was shown between the

presence and severity of extraneous spine calcification and falsely elevated L-spine BMD and T-scores (14). In the general population, qCT appears to be a more sensitive technique for the diagnosis of low bone mass and to correlate better with risk of fracture than DXA. However, qCT is not the method of choice for monitoring serial changes in BMD because of its inferior precision, relatively high radiation exposure, and higher cost than DXA (19,20).

The prevalence of vertebral abnormalities observed in patients with SCI may be compared with that in an able-bodied population. In our prior study, in those with SCI, 55% had mild to moderate degenerative joint disease (DJD) and 25% had severe DJD of the L-spine; in the control group, 40% had mild DJD and none had moderate or severe DJD of the L-spine (14). By categorizing the group with SCI by the severity of DJD, the patients with the most extensive disease were the ones who also had spuriously higher lumbar T-scores by PA DXA. Thus, it would appear that patients with SCI have an increased prevalence of abnormalities of the spine compared with the able-bodied population, possibly due to neuropathic spondylopathy (eg, osteophytes, microcompression fractures). Even with the recent studies appreciated, a lack of consensus and clinical confusion with regard to bone mass of the L-spine in patients with chronic SCI still persists. This is likely because in clinical practice the L-spine is still routinely imaged by the PA projection. Thus, relying on PA DXA alone to determine BMD of the axial skeleton is problematic and should be avoided. If one were to obtain radiographs of the L-spine to exclude extraneous calcification of the vertebrae, then it would be expected that PA DXA imaging would be acceptable, with the caveat noted that most individuals with long-standing SCI have degenerative changes of the spine. As reported in the literature, our study failed to consistently identify low bone mass and did not identify osteoporosis of the L-spine by PA DXA in individuals with chronic SCI, whereas LAT DXA appeared to capture the severity of the bone

Table 5. Correlations of Duration of Injury With Posterior-Anterior Lumbar Spine, Lateral Lumbar Spine, Total Hip, and Femoral Neck for the Bone Mineral Density and T- and Z-Scores

	BMD, N = 15		T-Score, N = 15		Z-Score, N = 15	
	R	P	R	P	R	P
L2 PA spine	−0.40	ns	−0.33	ns	−0.15	ns
L3 PA spine	−0.16	ns	−0.08	ns	0.13	ns
L2-L3 PA spine	−0.29	ns	−0.21	ns	0.00	ns
L2 LAT spine	−0.42	ns	−0.14	ns	0.07	ns
L3 LAT spine	−0.60	0.01	−0.47	0.07	−0.39	ns
L2-L3 LAT spine	−0.57	<0.05	−0.43	ns	−0.21	ns
Total hip	−0.61	0.01	−0.54	<0.05	−0.37	ns
Femoral neck	−0.61	0.01	−0.54	<0.05	−0.37	ns

BMD, bone mineral density; PA, posterior-anterior; LAT, lateral; L, lumbar vertebrae; and ns, not significant.

Figure 2. Relationship between lumbar spine and total hip bone mineral density (BMD) and T-scores with duration of injury in a subset of patients ($n = 9$) with duration of injury ≥ 18 months. Lateral L3: $BMD (g/cm^2) = 0.964 - 0.003 * X$; $r^2 = 0.57$; $P < 0.01$; and $T\text{-score} = 0.592 - 0.016 * X$; $r^2 = 0.47$; $P < 0.05$. Total hip: $BMD (g/cm^2) = 1.014 - 0.001 * X$; $r^2 = 0.52$; $P < 0.05$; and $T\text{-score} = -0.623 - 0.008 * X$; $r^2 = 0.46$; $P < 0.05$.

loss in a more reliable manner, as reflected in the significantly lower T-scores.

Because of its low level of radiation exposure and its reliable, facile performance, DXA has been widely used to determine BMD of the skeleton in patients with SCI. Using DXA imaging to diagnosis osteoporosis of the extremities in those with SCI is usually valid and useful. On the other hand, LAT DXA of the vertebrae would appear to be the preferred method of imaging, if the technical capacity is available to perform this measurement. A further refinement of the LAT L-spine is the midlateral measurement, which would serve to eliminate contributions from the superior and inferior vertebral endplates (eg, predominantly cortical bone contributions); however, normative data for T- and Z-scores for the LAT L-spine midlateral spine on the Lunar DXA machines does not exist, but such data and software are currently available on the Hologic QDR 2000 bone densitometer (Hologic, Inc, Waltham, MA) (16).

Because patients with SCI may engage in physical activities to strengthen their upper bodies, significant loss of bone mass of the vertebrae would be expected to place them at a heightened risk of vertebral compression fracture. As such, caution should be exercised with regard to exercise prescription until a reliable imaging technique can be applied to exclude significant loss of bone mass of the L-spine. Studies to determine the optimum imaging technique(s) to be applied to determine low bone mass of the spine, as well as to define the

specific parameters of bone loss for individual exercise prescription, should be areas of active investigation.

CONCLUSIONS

In contrast to much of the literature that has relied on diagnosing vertebral bone mass by PA DXA measurements, this study has demonstrated that a high proportion of patients with chronic SCI have significant bone loss of the L-spine. Rather than relying on the PA projection by DXA that captures the posterior cortical bone and potentially associated pathologic bony and vascular structures, the LAT L-spine appears to provide a more accurate representation of bone of the vertebral body. Because patients with SCI may engage in physical activities of the upper body, significant loss of bone mass of the vertebrae would be expected to place them at a heightened risk of vertebral compression fracture. Thus, one should consider applying a reliable imaging technique to exclude significant loss of vertebral bone mass when exercise prescription is being considered.

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