

## ORIGINAL ARTICLE

# Dual-energy X-ray absorptiometry overestimates bone mineral density of the lumbar spine in persons with spinal cord injury

WA Bauman<sup>1,2,3</sup>, E Schwartz<sup>1</sup>, ISY Song<sup>1</sup>, S Kirshblum<sup>4,5</sup>, C Cirnigliaro<sup>1</sup>, N Morrison<sup>1</sup> and AM Spungen<sup>1,2,3</sup>

<sup>1</sup>Veterans Affairs Rehabilitation Research and Development Center of Excellence for the Medical Consequences of Spinal Cord Injury, James J Peters Veterans Affairs Medical Center, Bronx, NY, USA; <sup>2</sup>Medical, Spinal Cord Injury and Research Services, James J Peters Veterans Affairs Medical Center, Bronx, NY, USA; <sup>3</sup>Department of Medicine and Department of Rehabilitation Medicine, Mount Sinai Medical Center, New York, NY, USA; <sup>4</sup>Kessler Institute for Rehabilitation, West Orange, NJ, USA and <sup>5</sup>Department of Physical Medicine and Rehabilitation, University of Medical and Dentistry/New Jersey, Newark, NJ, USA

**Background:** Bone mineral density (BMD) of the lumbar spine (L-spine) has been reported to be normal or increased in persons with chronic spinal cord injury (SCI).

**Objective:** To determine BMD of the L-spine by dual-energy X-ray absorptiometry (DXA) and quantitative computerized tomography (qCT) in men with chronic SCI compared with able-bodied controls.

**Design:** Cross-sectional, comparative study.

**Setting:** Clinical research unit, Veterans Affairs Medical Center, Bronx, NY, USA and Kessler Institute of Rehabilitation, West Orange, NJ, USA.

**Methods:** Measurements of the L-spine were made in 20 men with SCI and compared with 15 able-bodied controls. The DXA images were acquired on a GE Lunar DPX-IQ. The qCT images of the L-spine were acquired on a Picker Q series computerized tomographic scanner.

**Results:** The mean ages for the SCI and control groups were  $44 \pm 13$  vs  $42 \pm 9$  years, and the duration of injury of the group with SCI was  $14 \pm 11$  years. There were no significant differences between the SCI and control groups for L-spine DXA BMD ( $1.391 \pm 0.210$  vs  $1.315 \pm 0.178$  g/m<sup>2</sup>) or for L-spine DXA T-score ( $1.471 \pm 1.794$  vs  $0.782 \pm 1.481$ ). L-spine qCT BMD was significantly lower in the SCI compared with the control group ( $1.296 \pm 0.416$  vs  $1.572 \pm 0.382$  g/m<sup>2</sup>,  $P=0.05$ ); the T-score approached significance ( $-1.838 \pm 1.366$  vs  $-0.963 \pm 1.227$ ,  $P=0.059$ ). Subjects with moderate degenerative joint disease (DJD) had significantly higher T-scores by DXA than those without or with mild DJD.

**Conclusion:** Individuals with SCI who have moderate to severe DJD may have bone loss of the L-spine that may be underestimated by DXA, reducing awareness of the risk of fracture.

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**Keywords:** spinal cord injury; bone mineral density; vertebral body; quantitative computerized tomography; dual-energy X-ray absorptiometry; degenerative joint disease

## Introduction

Osteoporosis is a predictable occurrence below the level of injury in individuals with chronic spinal cord injury (SCI), especially of the long bones that predispose to fracture.<sup>1–6</sup> Of note, the literature is replete with reports of cross-sectional studies that have found, contrary to the extremities and other bony structures, that the vertebral column does not seem to lose bone mass after paralysis but, rather, tends to gain bone mass with age and/or longer duration of injury.<sup>1,7–11</sup> Various mechanisms have been proposed to explain why the

vertebral spine does not lose bone mass, and these include continued application of gravity-related forces, the effects of prolonged seated posture and a different mechanical function of the spine than that of the limbs.

Two reports have previously challenged the notion that the vertebral bodies are spared from bone loss after paralysis.<sup>12,13</sup> Both studies have suggested that the absence of osteoporosis of the spine is a spurious finding of dual-energy X-ray absorptiometry (DXA).<sup>12,13</sup> Because of its facile application and low level of radiation exposure, DXA has been widely used to determine bone mineral density (BMD) of the hip and lumbar spine (L-spine) in the general population, and it has generally permitted the prompt and reproducible diagnosis of osteoporosis. However, the anteroposterior (AP) determination of the L-spine bone mass has

Correspondence: Dr WA Bauman, Center of Excellence for the Medical Consequences of Spinal Cord Injury, Room 1E-02, James J Peters Veterans Affairs Medical Center, 130 West Kingsbridge Road, Bronx, NY 10468, USA.  
E-mail: william.bauman@va.gov

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been recognized to include in its field, when present, the measurement of extraneous calcification. In the general able-bodied population, extra-vertebral calcification may obscure the diagnosis of osteoporosis.<sup>14–16</sup> DXA may also overestimate BMD of the L-spine in persons with SCI because of the presence of neuropathic calcification.<sup>12,13</sup>

Imaging the spine with qCT permits the observer to restrict the field of interest to the mid-vertebrae, rather than the surrounding structures. Thus, qCT holds the potential to permit differentiation between the L-spine medullary portion of trabecular BMD from that of regions repleted with cortical bone and proximate areas in persons with SCI, which may spuriously elevate bone mass measurement. The ability to differentiate spuriously increased from actually decreased spine BMD is of importance as any exercise prescription that increases the forces on vertebrae that are osteoporotic should be avoided to reduce the risk of compression fracture. In persons with SCI and able-bodied controls, we compared two imaging techniques of the L-spine: DXA and quantitative computerized tomography (qCT).

## Methods

This was a cross-sectional and comparative study. In the able-bodied controls, height and weight were measured in the standing position. In the group with SCI, height was measured while lying in the supine position and weight was measured on a Weight-Tronix scale (Scale Electronics Development, New York, NY, USA). Body mass index (BMI) was calculated as body weight in kilograms (kg) divided by height in meters squared ( $m^2$ ).

### Subjects

Twenty male subjects with SCI (10 with paraplegia and 10 with tetraplegia) who were available for study (for example, convenience sample) and 15 age- and height-matched, able-bodied men who served as controls were recruited for study. Subjects with SCI were recruited from SCI Service of the James J Peters Veterans Affairs Medical Center, Bronx, NY, USA and the Kessler Institute of Rehabilitation, West Orange, NJ, USA; controls were recruited from the able-bodied veteran population, general community and hospital staff. The ethnic distribution in the SCI group was 7 Caucasians, 8 African-Americans and 5 Latinos; in the control group, the ethnic distribution was 1 Caucasian, 11 African-Americans, 1 Latino and 2 Asians. Participants were excluded from the study if they had a history of earlier bone disease (for example, Paget's disease, hyperparathyroidism, osteoporosis, heterotopic ossification, etc.) or any condition predisposing to osteoporosis (for example, alcohol abuse, anabolic or glucocorticoid steroid administration, hyperthyroidism, Cushing's disease or syndrome and severe underlying chronic disease), other than SCI. Persons with surgical hardware of the spine were excluded from study participation. There was no attempt to include or exclude persons with DJD of the spine from study participation. Institutional review approval was obtained from the James J Peters Veterans Affairs Medical Center and the Kessler Institute of Rehabilitation before study participation.

### DXA and qCT imaging

Each subject had a single DXA scan performed. The DXA images were acquired on a GE Lunar DPX-IQ, with the region of interest (ROI) (L-spine) isolated for quantification of regional BMD (Lunar Model DPX, version 3.6, Madison, WI, USA).<sup>17</sup> The scans were acquired by trained technicians. Using a phantom, scanned 38 consecutive times over a 12-month period, day-to-day DXA variation was  $<1\%$  (C.V. = 0.06); in 15 subjects who were not participants in this study, day-to-day variability was found to be  $<1.5\%$  (C.V. =  $1.493 \pm 0.014$ ; 95% C.I.: lower = 1.11%, upper = 1.9%). Measurements for DXA were carried out on the same day or within 1 week of the qCT scan. Software algorithms were applied to isolate the ROI (Lunar instrumentation manual).<sup>15</sup> The L-spine ( $L_1$  to  $L_4$  region) was displayed graphically and the operator adjusted the final-cut lines on each subject. All cuts were performed by the same technician to avoid inter-rater variability.

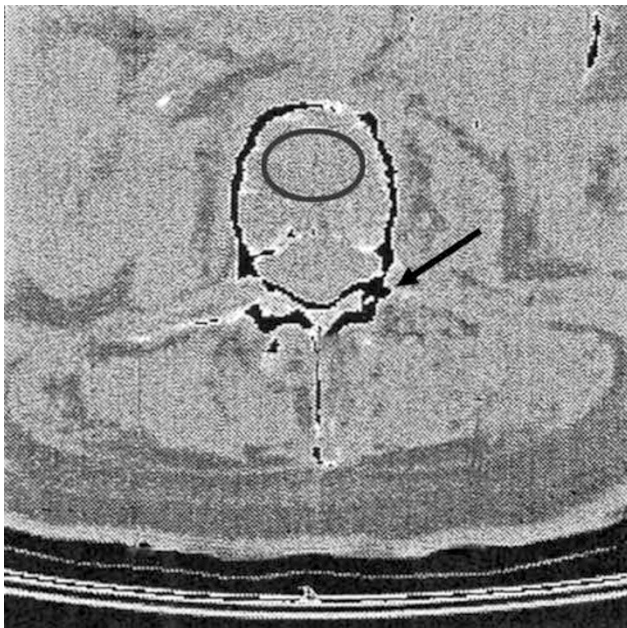
The subjects were studied with the Picker Q-Series computerized tomographic (CT) Scanner and Q-Series Bone Mineral Analysis Program (Q-BMAP) using the Q-BMAP workstation for analysis in which the BMD value (mg/cm of equivalent bone density) was calculated. The technique captures BMD of medullary portion of trabecular bone of the L-spine, excluding cortical regions, as well as excluding regions of potential osteophyte formation and vascular calcification. Each subject had a single qCT scan performed. The subject was centered on the qCT scanning table in the supine position with their knees flexed to permit the spine to be flattened in an effort to minimize the need for individual Gantry angles for each lumbar vertebrae; however, the fifth lumbar vertebra required a different Gantry angle for parallel sections. A restraint was placed around the knees to reduce motion artifact. The study was performed at 140 KV, 100 MA and targeted to include L-spine and retro-spinal muscle and fat. Vertebral bodies were acquired from  $L_1$  to  $L_5$ , and included 4–5 sections through the pedicle level; the scan was performed over 2 s with an 18 cm field size and a slice thickness of 5 mm oriented parallel to the vertebral end plate. Scans were acquired by several radiology technicians but processed by a single radiology technician. A radiologist reviewed the films. Two sections were selected as the most representative of the medullary portion of each of the vertebral body (Figure 1). In the Picker Q-BMAP software, the technique uses the patient's muscle and fat tissue as internal reference standard as the X-ray attenuation properties of these soft tissues remains relatively constant.<sup>18</sup> The Q-BMAP software uses the measured CT values for fat ( $-85.7$  Hounsfield units (HU)) and muscle (27.1 HU), which permit definition of a reference line to allow the conversion of the CT values for trabecular bone into equivalent bone density (mg/cc). At this time, images were transferred from a Q-Series scanner to a Q-Series BMAP system with single image display in which the selected image of trabecular bone, ROI, was circumscribed by computerized localization for determination of BMD. The Q-BMAP software also provided a T-score, which was calculated by determining the deviation of the BMD from that of young normal values, divided by the standard deviation (s.d.) of the reference population. The

most recent International Society for Clinical Densitometry guideline does not permit the clinical diagnosis of osteoporosis from T-scores derived from qCT as these values are not equivalent to the T-scores derived by DXA.<sup>19</sup>

The L-spine was evaluated by computerized tomographic scan for the degree of DJD. A semiquantitative technique was used to grade the severity of DJD because mild, moderate or severe. An experienced radiologist performed the grading of the L-spine of each subject.

#### Statistical analyses

The results are expressed as mean plus or minus s.d. of the mean. An unpaired T-score was used to determine the presence of significance between the group with SCI and the control group for L-spine BMD and T-scores by DXA and qCT. Although the T-scores derived from qCT are not equivalent to those derived by DXA, this does not preclude



**Figure 1** Computed tomographic image of the lumbar spine at the level of the pedicle (arrow). The region of interest (ROI) is drawn within the trabecular lumbar vertebral body, excluding cortical bone and extraneous calcification, if present. Bone mineral density (BMD) is obtained by measuring the Hounsfield units in the ROI and comparing the value to units from soft tissue.<sup>19</sup>

**Table 1** Characteristics of the subjects

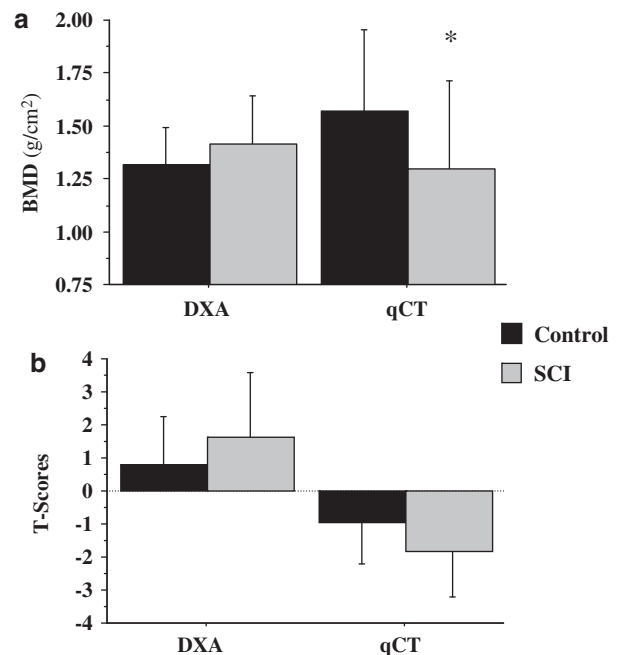
	SCI	Control
Count	20	15
Age (years)	44 ± 13	42 ± 9
DOI (years)	14 ± 11	NA
Height (m)	1.80 ± 0.09	1.79 ± 0.09
Weight (kg)	88.9 ± 16.6	96.6 ± 21.7
BMI (kg/m <sup>2</sup> )	27.4 ± 4.7	30.2 ± 6.0

Abbreviations: BMI, body mass index; NA, not applicable; SCI, spinal cord injury; DOI, duration of injury.

a relative comparison between values obtained from each method. A paired T-test was applied to determine significance between imaging methods for T-scores. A  $\chi^2$  analysis was used to determine the significance of the distribution differences between groups for DJD. A two-factor (DJD, method) analysis of variance was applied for comparisons of T-scores, and Fisher-protected least squares differences were used for *post hoc* comparisons. Linear regression analysis was applied to determine the relationship between L-spine BMD and level of lesion (each level of lesion was assigned a number to correspond to vertebral segment from 1 (C<sub>1</sub>) to 25 (L<sub>4</sub>)).

#### Results

The groups were well-matched for age, height, weight and BMI (m/kg<sup>2</sup>) with no significant differences (Table 1). Persons with SCI had an average duration of injury of 14 ± 11 years (range: 1–31 years) (Table 1). There was no significant difference between the SCI and control groups for L-spine DXA BMD (1.391 ± 0.210 vs 1.315 ± 0.178 g/m<sup>2</sup>; Figure 2a) or for L-spine DXA T-score (1.471 ± 1.794 vs 0.782 ± 1.481; Figure 2b). However, L-spine qCT BMD was significantly lower in the SCI compared with the control group (1.296 ± 0.416 vs 1.572 ± 0.382 g/m<sup>2</sup>, *P* = 0.05; Figure 2a) and the T-score approached significance (−1.838 ± 1.366 vs −0.963 ± 1.227, *P* = 0.059; Figure 2b). Six

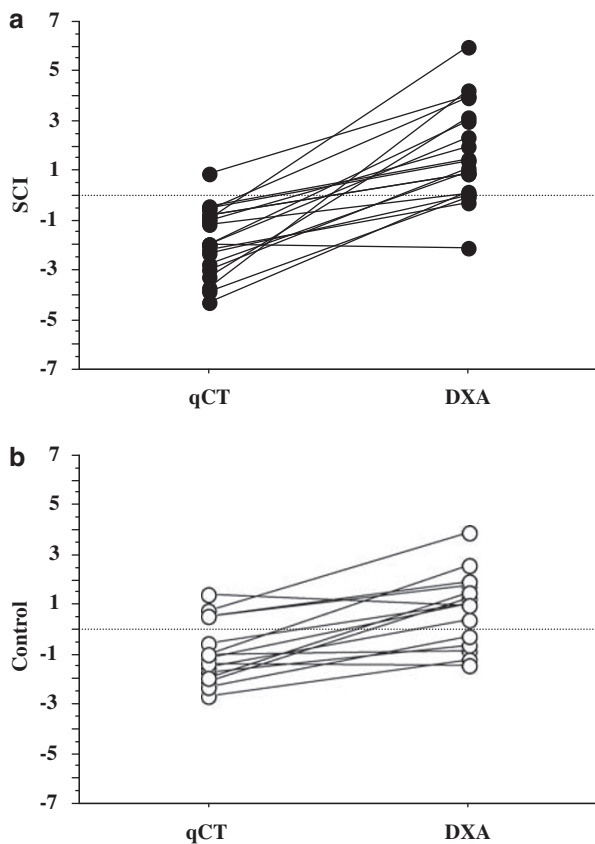


**Figure 2** Mean values for bone mineral density (BMD) and T-scores of the lumbar spine (L-spine). The solid boxes represent the control group, and the lightly shaded boxes represent the spinal cord injury (SCI) group. (a) BMD of the L-spine by dual-energy X-ray absorptiometry (DXA) (1.315 ± 0.178 vs 1.391 ± 0.210 g/m<sup>2</sup>; not significant (NS)) and quantitative computerized tomography (qCT) (1.572 ± 0.382 vs 1.296 ± 0.416, \**P* = 0.05) (b) T-scores of the L-spine by DXA (0.782 ± 1.481 vs 1.471 ± 1.794); NS) and qCT (−0.963 ± 1.227 vs −1.838 ± 1.366, *P* = 0.059).

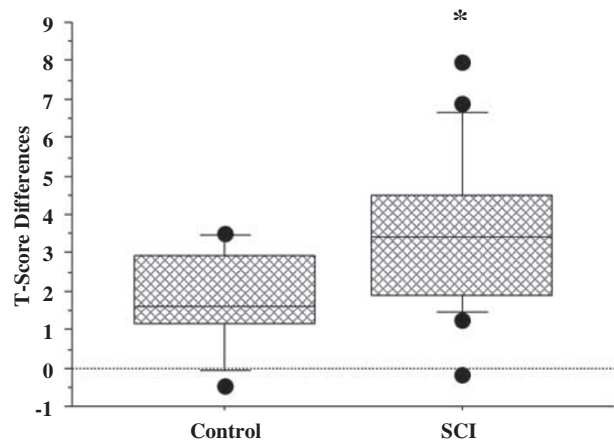
subjects with SCI had T-scores  $\leq -2.5$  s.d. below the mean by qCT, whereas all had T-scores  $> -2.5$  s.d. below the mean by DXA (Figure 3). All control subjects had T-scores  $> -2.5$  s.d. below the mean by DXA, and only one subject had T-scores  $\leq -2.5$  s.d. below the mean by qCT (Figure 3).

Of the 20 subjects with SCI, 11 had mild or moderate DJD and 5 had severe DJD, whereas only 6 of 15 control subjects had mild DJD ( $\chi^2_{(2)} = 7.84, P < 0.02$ ). The median T-score difference (DXA T-score minus qCT T-score) was significantly higher in those with SCI than that of controls ( $3.5 \pm 2.0$  vs  $1.7 \pm 1.3, P < 0.01$ ) (Figure 4). The effect of the severity of DJD on the T-score by DXA was evident when the groups were stratified by the extent of disease. Those with moderate to severe DJD, classifications only present in the SCI group in our limited study, had significantly higher T-scores by DXA than those without or with mild DJD, and significant differences for T-scores between DXA and qCT were noted for group by severity of DJD (Figure 5).

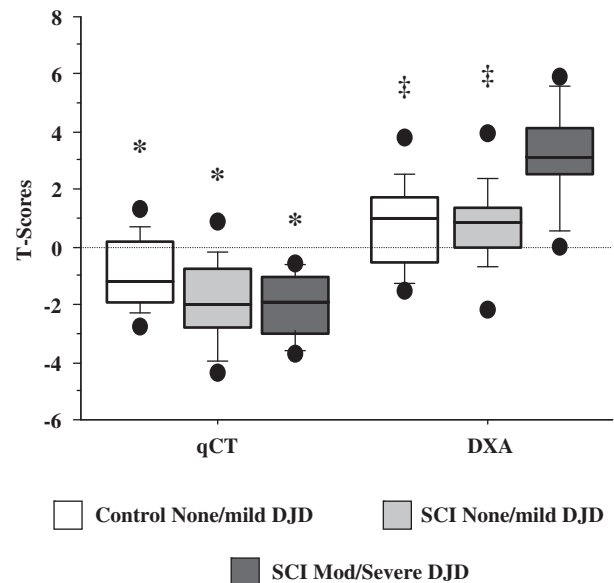
A significant relationship was evident for L-spine BMD by qCT and level of lesion ( $r = 0.46, P < 0.05$ ), with the higher



**Figure 3** T-scores of the lumbar spine for quantitative computerized tomography (qCT) and dual-energy X-ray absorptiometry (DXA) by subject. Lines connect individual subjects. (a) Spinal cord injury (SCI) subjects are represented by the solid circles (●). All subjects with SCI had T-scores  $> -2.5$  s.d. below the mean by DXA, and six SCI subjects had T-scores  $\leq -2.5$  s.d. by qCT. (b) The able-bodied controls are represented by the open circles (○). All control subjects had T-scores  $> -2.5$  s.d. below the mean by DXA, and only one able-bodied subject had a T-scores  $\leq -2.5$  s.d. below the mean by qCT.



**Figure 4** Box plots of the differences between lumbar spine T-scores (dual-energy X-ray absorptiometry T-score minus quantitative computerized tomography T-score). Each horizontal line in the plot of the controls and subjects with spinal cord injury (SCI) represents a percentile (from bottom to top: 10th, 25th, 50th, 75th and 90th percentile) for the T-score difference. The 25th to the 75th percentiles are represented by a cross-hatched box. There is a significant difference between the median values (middle horizontal line) for the SCI group and the control group ( $3.5 \pm 2.0$  vs  $1.7 \pm 1.3, *P < 0.01$ ). The solid circles (●) represent outliers.



**Figure 5** Box plots of all subjects (spinal cord injury (SCI) and control) categorized by severity of lumbar spine degenerative joint disease (DJD). Each horizontal line in each plot represents a percentile (from bottom to top: 10th, 25th, 50th, 75th and 90th percentile) for the T-scores. The 25th to the 75th percentiles are represented by boxes with the following designations: open box = control subjects without or with mild DJD, lightly shaded box = SCI subjects without or with mild DJD and darkly shaded box = SCI subjects with moderate or severe DJD.  $*P < 0.001$  comparing T-scores for dual-energy X-ray absorptiometry (DXA) with quantitative computerized tomography (qCT) within subgroups categorized by degree of DJD (for example, mild, moderate and severe).  $†P < 0.002$  for T-scores differences among the subgroups (control subjects without or with mild DJD, SCI subjects without or with mild DJD and SCI subjects with moderate or severe DJD). The solid circles (●) represent outliers. Note that the subgroup with the most severe DJD had the highest T-score value by DXA.

cord lesions generally having lower L-spine BMD. No such relationship was shown for L-spine BMD by DXA and level of lesion. Of note, BMD of the L-spine of subjects with tetraplegia was significantly lower than that of able-bodied controls ( $1.128 \pm 0.310$  vs  $1.572 \pm 0.099$ ,  $P < 0.01$ ), and this comparison approached significance for those with paraplegia ( $1.464 \pm 0.455$  vs  $1.572 \pm 0.099$ ,  $P = 0.069$ ).

## Discussion

There has been a lack of consensus and clinical confusion with regard to bone mass of the L-spine in persons with chronic SCI. Despite the presence of accepted risk factors for osteoporosis of advancing age, menopause and duration of immobilization, earlier studies employing standard DXA imaging techniques alone have consistently reported an absence of vertebral bone loss, or, in some reports, even increased vertebral bone mass.<sup>1,14,20</sup> Our findings showed that DXA failed to identify osteopenia and osteoporosis of the L-spine in individuals with chronic SCI. If the L-spine is measured by qCT, men with chronic SCI have significant loss of spine bone mass, as they do of the extremities below the level of lesion.<sup>1,3,8,9,11</sup> Generally, earlier studies that have relied on AP DXA imaging of the lumbar vertebrae may be presumed to have captured extraneous calcification of, and associated with, the spine, thus providing spurious findings of preservation of the bone mass.

In 1988, Biering-Sorensen reported that although bone mineral content of the femoral neck and shaft and proximal tibia were significantly reduced in persons with SCI, there seemed 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.<sup>8</sup> Employing AP DXA as the methodology to acquire regional BMD, Leslie and Nance<sup>10</sup> compared 14 men with chronic SCI with 46 men with various endocrine disorders that predispose to bone loss (for example, exogenous steroid administration, hypogonadism, hyperthyroidism and other predisposing conditions) and idiopathic osteoporosis.<sup>10</sup> Although persons with SCI had marked femoral neck bone loss (86% of age-matched normal), these individuals had no evidence of L-spine loss (102% of age-matched normal). In contrast, the patients with endocrine disorders or idiopathic osteoporosis had a disproportionate demineralization of the spine (82% of age-matched normal) and minimal loss of BMD of the femoral neck (98% of age-matched normal). Using 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 post-menopausal women.<sup>11</sup> Our findings in men with SCI raise the distinct possibility that in women with SCI the apparent increase of L-spine BMD measured by DXA may have been due to extraneous calcification.

Jaovisidha *et al.*<sup>12</sup> performed a correlation analysis of vertebral levels L<sub>1</sub>–L<sub>4</sub> between AP radiographs of the L-spine and DXA in 116 persons with chronic SCI. 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 because of secondary progressive skeletal abnormalities that served to prevent the identification of significant bone loss. Liu *et al.*<sup>13</sup> studied a cohort of 64 persons with chronic SCI by qCT of the L-spine, and they also investigated a subgroup of 29 of the 64 persons using both qCT and DXA. In the total group, the Z-scores derived by qCT were  $-2.0 \pm 1.2$  of historic age-matched controls; in the subgroup in which both imaging techniques were performed, the qCT Z-score was  $-2.4 \pm 1.1$  and for DXA,  $1.3 \pm 2.3$  above the mean, which is quite similar to the finding reported herein.<sup>13</sup> Indeed, in the general population qCT seems to be a more sensitive technique for the diagnosis of osteopenia and to correlate better with fracture risk than that of DXA.<sup>21,22</sup> However, qCT is not the method of choice for monitoring serial changes in BMD owing to its inferior precision, relatively high radiation exposure, more difficult positioning, longer duration of scan and higher cost than DXA.<sup>23,24</sup>

Of note, a correlation was shown between L-spine BMD by qCT and level of lesion. The subjects with higher levels of lesion generally had lower L-spine bone density. It may be speculated that higher lesions, especially if associated with greater motor impairment, would have greater degrees of impairment of the trunk musculature, and thus less forces associated with stress and strain due to muscular contraction on the vertebrae.

In an able-bodied population of 750 men and 750 women studied for moderate or severe deformities of the spine, 8% of men and 7% of women had a moderate deformity of the spine, whereas 4% of men and 8% of women had a severe deformity of the spine.<sup>25</sup> In those with SCI, 55% (11 of the 20 subjects) had mild to moderate DJD and 25% (5 of the 20 subjects) had severe DJD of the L-spine. In contrast, in the control group, 40% (6 of the 15 subjects) had mild DJD and none had moderate or severe DJD of the L-spine. As such, both from our study and from a comparison with the general literature, it would appear that persons with SCI have an increased prevalence of abnormalities of the spine.<sup>12,13</sup> BMD measurements of the L-spine derived by qCT and DXA are acquired by different techniques and, in addition, are not measuring the same regions of interest. However, in the absence of confounding effects, one would have expected the T-scores to be somewhat comparable. Owing to the greater disparity of the L-spine T-scores between DXA and qCT for the group with SCI compared with the control group, it may have been expected that those with SCI would have had increased extraneous calcification in the imaging field. By categorizing the group with SCI by the severity of DJD, the subjects with the most extensive disease were also the ones who had spuriously higher lumbar T-scores by DXA.

The literature of skeletal bone mass in persons with SCI has largely relied on the accuracy of DXA to diagnose osteoporosis. Using DXA imaging to diagnose osteoporosis of the extremities in those with SCI is usually valid and useful. However, relying on AP DXA alone to determine BMD of the axial skeleton is problematic. Because of the apparent increased likelihood of osteophytes, vascular calcification, microcompression fractures and other skeletal abnormalities in persons with SCI, relying solely on AP DXA measurement of vertebral body density should be avoided. Quantitative CT

or possibly, as suggested in the literature, lateral or midlateral DXA of the spine, if the technical capacity is available to perform this measurement, are the preferred methods of imaging of the L-spine in individuals with degenerative changes. An alternative approach before performing DXA imaging may be to obtain radiographs of the L-spine to exclude extraneous calcification. Otherwise, the clinician may be misled to believe that lumbar vertebral BMD is normal or even increased for age, and thus underestimate the risk of vertebral fracture.

## Conclusion

In contrast to the majority of literature that has relied on diagnosing vertebral bone mass by DXA, this study has shown that a proportion of men with chronic SCI, especially those with higher cord lesions, have significant bone loss of the L-spine. A clear association has been shown between the presence and severity of extraneous spine calcification, and spuriously elevated L-spine BMD and T-scores. The use of qCT permits isolation and examination of the medullary portion of trabecular bone of the vertebral body, rather than relying on the AP projection by DXA that captures the posterior cortical bone and potentially associated pathological bony and vascular structures. Because persons 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, it is prudent to consider avoiding exercises that place large compressive forces on the spine until a reliable imaging technique can be applied to exclude significant loss of bone mass of the L-spine.

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