Quantitative Computed Tomography in the Evaluation of Spinal Osteoporosis Following Spinal Cord Injury

C. C. Liu¹, D. J. Theodorou¹, S. J. Theodorou¹, M. P. Andre¹, D. J. Sartoris¹,², S. M. Szollar³, E. M. Martin¹ and L. J. Deftos⁴
¹Department of Radiology, University of California San Diego and Veterans Affairs Medical Center, San Diego; ²Department of Radiology, University of California San Diego and Thornton Hospital, La Jolla, San Diego; ³Department of Orthopedic Rehabilitation, University of California San Diego and Veterans Affairs Medical Center, San Diego; and ⁴Department of Medicine and Division of Endocrinology, University of California San Diego and Veterans Affairs Medical Center, San Diego, California, USA

Abstract. Disuse osteoporosis occurs in the lower extremities of patients with spinal cord injury (SCI). However, spinal osteoporosis is not usually observed in these patients. We investigated lumbar spine bone mineral density (BMD) in SCI patients using single energy quantitative computed tomography (QCT) and dual-energy X-ray absorptiometry (DXA). Our study population consisted of 64 patients with long-standing SCI. Spine BMD (g/cm²) was assessed by QCT at four vertebrae ranging from T11 to L4 with single mid-vertebral CT slices 1 cm thick parallel to the vertebral end-plates. Confounding variables affecting normal trabecular bone pattern, such as compression fractures, surgical hardware or fat replacement, were excluded. For a subset of 29 patients, DXA values of the spine and femoral neck were also measured, and QCT and DXA Z-scores were compared. On the average, the 64 SCI patients had Z-scores 2.0 ± 1.2 below those of age-matched controls. In the subset of 29 patients with both QCT and DXA measurements, the QCT and DXA Z-scores were 2.4 ± 1.1 below and 1.3 ± 2.3 above the mean, respectively (p < 0.0001). Our results indicate that QCT reveals osteoporosis of the spine after SCI, in contrast to DXA. We postulate that QCT is more valuable for evaluating spinal osteoporosis following SCI than DXA and thus recommend QCT for spinal BMD studies in SCI.

Keywords: Bone disease; Disuse osteoporosis; Dual-energy X-ray absorptiometry; Imaging; Single-energy quantitative computed tomography; Spinal cord injury

Introduction

The presence and extent of skeletal demineralization in patients with spinal cord injury (SCI) remains controversial [1]. Neuronal as well as musculoskeletal factors may participate in this debilitating process [2,3]. Disuse osteoporosis is known to occur in these patients [2]. In particular, demineralization has been demonstrated in the lower extremities and iliac crests of SCI patients [1–4]. However, the spinal bone mineral density (BMD) in these patients is reported as preserved, and spinal osteoporosis following SCI is not usually observed [1,3,5–13]. A maintained spinal BMD in SCI might be due to the continued muscle activity and/or weight-bearing during use of a wheelchair [8].

Dual-energy X-ray absorptiometry (DXA) has been the bone densitometry technique of choice in evaluating spinal BMD in SCI patients [1,3,5–13]. However, confounding variables may complicate DXA spinal BMD measurement, producing falsely elevated results [13–16]. In view of confounding factors such as spinal
heterotopic bone formation and neuropathic changes, which often exist in SCI patients [2,17,18], we used single-energy quantitative computed tomography (QCT) to study BMD in the spine of SCI patients and compared this method with DXA.

Subjects and Methods

Our study population consisted of 64 male SCI patients with ages ranging from 20 to 98 years (mean age 52 years) from the SCI unit at the Veterans Affairs Medical Center, San Diego, California, USA. All the patients had traumatic SCI. We employed the single-energy QCT techniques and corresponding data bases developed at the University of California, San Francisco [19,20]. A single midvertebral CT slice with a thickness of 1 cm was acquired in a plane parallel to the vertebral endplates. Simultaneous pixel calibration was performed using a mineral-equivalent reference phantom placed beneath the patient during scanning. In each patient, spinal BMD measurements were obtained in four thoracolumbar vertebrae (T11 to L4), using a CT scanner equipped with software for quantitative studies (Picker PQ-5000, Cleveland, OH). In selecting the vertebral levels to study, we emphasized the lumbar spine unless confounding variables such as compression fractures, trabecular heterotopic bone or surgical hardware in the lumbar spine were present. Then that particular level was excluded and a thoracic vertebral level (either T11 or T12) was chosen for the BMD calculation, necessary for 15% of vertebra. A subset of 29 patients ranging in age from 23 to 98 years (mean 52 years) had lumbar spine and femoral neck evaluation of BMD using DXA (Lunar DPX, Madison, WI) as well. DXA studies of the lumbar spine were performed from the L1 to L4 spinal levels in the frontal plane and DXA studies of the femoral neck were performed in the frontal plane over the region of the midfemoral neck. The QCT BMD values (g/cm²) and DXA BMD values (g/cm²) were calculated and compared with values of the age-matched controls derived from the population studies of Genant et al. [19]. Subsequently, they were converted to Z-scores (the calculated BMD value minus the age-matched control value, divided by the standard deviation). In the subset of 29 patients, Z-scores derived from QCT lumbar spine (QCT-L), DXA lumbar spine (DXA-L) and DXA femoral neck (DXA-F) studies were correlated. In addition, patients with QCT-L BMD studies were stratified according to the severity and spinal level of injury into eight groups, namely complete SCI (loss of all motor function), incomplete SCI, paraplegic (injury below C7), quadriplegic (injury at and above C7), complete paraplegic, incomplete paraplegic, complete quadriplegic, and incomplete quadriplegic patients. In each individual case, the QCT BMD values were averaged over all vertebral bodies. Statistical analysis of data was performed with a paired t-test (Student’s t-test).

Results

The average QCT lumbar BMD of the 64 patients was 2.0 ± 1.2 (Z-score) below the mean of age-matched controls. For the subset of 29 patients who had DXA lumbar and femoral neck BMD results, the QCT lumbar spine BMD was 2.4 ± 1.1 below the mean, while the DXA lumbar spine BMD for the same population was 1.3 ± 2.3 above the mean (p < 0.0001) (Fig. 1). The trend for DXA lumbar spine BMD was such that the older the injury, the higher the BMD value. The opposite was true for the QCT lumbar spine studies: the older the injury, the lower the BMD. The average DXA femoral neck BMD was 0.9 ± 1.6 (Z-score) below the mean. The data had a trend similar to that of QCT lumbar spine studies when plotted against injury duration (R = 0.4 for the linear regression) (Figs 2, 3).

The QCT lumbar spine group was divided into complete (Comp) and incomplete (Incomp) injuries, and re-stratified into paraplegic (Para) and quadriplegic (Quad) groups. The trend of BMD loss in decreasing order of severity was: Comp Quad, Incomp Para, Comp Para and Incomp Quad. The average, standard deviation of average, and average duration of injury of each subgroup are summarized in Table 1 and illustrated in Fig. 4. Despite any trends, there were no significant differences among these groups, perhaps due to their small size.

Examples of the procedures used in this study are illustrated in Figs. 5 and 6. The BMD values (g/cm² for DXA and g/cm² for QCT) were plotted against patients’ age with superimposed age-matched controls. (Figs 7–9). Three patients were excluded from the study: two had anomalous (negative) QCT lumbar spine BMD results in one or more vertebral bodies, and the other patient had extensive heterotopic bone formation occupying much of the trabecular space. In this patient, the QCT BMD Z-score was 2.2 after 37 years of injury (complete paraplegia).

![Fig. 1. Z-scores for lumbar spine QCT (QCT-L), femoral neck DXA (DXA-F) and lumbar spine DXA (DXA-L) in 29 patients with spinal cord injury (SCI). Summarized are the Z-scores and standard errors of three measurements performed on 29 selected patients. The average Z-score is negative for QCT-L and DXA-F, but positive for DXA-L.](image-url)