Original Article

Intensive exercise may preserve bone mass of the upper limbs in spinal cord injured males but does not retard demineralisation of the lower body

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Study design: Cross-sectional study comparing a group of active spinal cord injured (SCI) males carefully matched for age, height, and weight with active able-bodied male controls.

Objectives: To compare bone mass of the total body, upper and lower limbs, hip, and spine regions in active SCI and able-bodied individuals.

Setting: Outpatient study undertaken in two centres in New Zealand.

Methods: Dual energy X-ray absorptiometry (DEXA) scanning was used to determine bone mass. Questionnaires were used to ascertain total time spent in weekly physical activity for each individual. The criterion for entry into the study was regular participation in physical activity of more than 60 min per week, over and above that required for rehabilitation.

Results: Seventeen SCI and their able-bodied controls met our required activity criterion. Bone mineral density (BMD) values of the total body and hip regions were significantly lower in the SCI group than in their controls ($P=0.0001$). Leg BMD and bone mineral content (BMC) were also significantly lower in the SCI group ($P=0.0001$). By contrast, lumbar spine BMD and arm BMD and BMC did not differ between the SCI and control groups. Arm BMD and BMC were greater (not significant) than the reference norms (LUNAR database) for both groups.

Conclusion: Intensive exercise regimens may contribute to preservation of arm bone mass in SCI males, but does not prevent demineralisation in the lower body.

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Introduction

Intermittent load bearing is imperative to the maintenance of bone mass.^{1–3} The loss of bone mineral from the skeleton has been difficult to counter in microgravitational environments, such as spinal cord injury,^{4–7} bedrest,^{8–10} and spaceflight.^{11,12} Under these conditions the loss of bone mass is more pronounced in the lower, weight-bearing, limbs and remains relatively unchanged in the trunk. In spinal cord injured (SCI) however, demineralisation is also influenced by the level and completeness of the spinal cord lesion, and duration of injury (DOI).^{5,13,14}

In the able-bodied population, exercise has been shown to have an osteogenic influence, with the greatest bone mass preservation or increase at sites which are loaded intermittently.^{15–18} Morel *et al*¹⁵ found arm BMD to be greatest in sportsmen involved in rugby, fighting sports, basketball, volleyball, handball and bodybuilding, and the increased bone mass in the dominant arm of tennis players is well documented.¹⁹ Similarly exercise has been used to reduce the extent of skeletal demineralisation in both spaceflight,²⁰ and in the spinal cord injured population.^{21–23} However, results of load-bearing exercise in a microgravitational environment have been equivocal.^{11,12,20,21,24,25}

The purpose of this study was to compare bone mineral density of the total body, upper limbs, lower

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limbs, hip, and spine regions in a group of very active spinal cord injured adult males with values obtained in active able-bodied controls, carefully matched for age, height, and weight.

Methods

The study protocol was approved by the Health Funding Authority Ethics Committees in Otago (Protocol number: 97/10/084) and Canterbury (Protocol number: 99/05/067). Twenty spinal cord injured males (age range 17–52 years) were invited to participate. Each SCI subject was age- (within 5 years), height- (within 5 cm), and weight-matched (within 5 kg) with an able-bodied male control. A questionnaire was then used to ascertain time spent in total weekly physical activity (min), and the variety of physical activities participated in by each subject. In New Zealand, standard rehabilitation guidelines include regular participation in light weight training, theraband exercises, standing, and low intensity wheelchair pushing. Those SCI individuals reporting physical activity levels in excess of 60 min per week, over and above that undertaken for rehabilitation were selected for bone mass assessment. Seventeen SCI and their able-bodied controls met the desired criterion. We endeavoured to match our SCI individuals with able-bodied controls who undertook similar activity patterns (duration and frequency and activities which included upper limb loading exercise). Three SCI did not reach the minimum weekly physical activity criterion, and therefore they and their controls were excluded from the present analysis.

In the SCI group, pre-injury height was self-reported and also directly measured using the electronic ruler function of the LUNAR DPX-L scanner software. In the able-bodied group, height was measured both using a wall-mounted stadiometer (Holtain Ltd, Crosswell, Crymych, UK) and the electronic ruler function of the LUNAR DPX-L scanner software. Pearson correlations between scanner height measurements and the self-reported and measured values of the SCI group and controls were determined. However, in the present study the electronic ruler measurements of height have been used for all participants to maintain uniformity. Body weight was taken as the sum of total fat tissue, total lean tissue, and total bone mineral content from the total body dual energy X-ray absorptiometry (DEXA) (LUNAR DPX-L, Lunar Corporation, Madison, WI, USA) scan for each participant.

Bone mineral density (BMD, g/cm³) of the total body, arms, legs, left hip (femoral neck, Wards triangle and trochanter), and lumbar spine (L2–L4) were measured by DEXA. The arm region includes the humerus, radius, ulna and all the hand bones, while the leg region includes the femur, tibia, fibula and all the foot bones. Separate scans of the total body, left hip, and lumbar spine were taken. In our laboratory, *in vivo* coefficients of variation (CV's) at different sites

using Lunar total body software version 1.35 (for 10 repeat scans performed on different days) are: total body BMC 0.84%, total body BMD 1.06%, arm BMC 1.96%, arm BMD 1.33%, legs BMC 1.48%, and legs BMD 1.93%. Our CV's for total body, arm, and leg BMD are similar to those published.²⁶ For specific regional scans (software v1.35), the *in vivo* CV's in our laboratory are: lumbar spine BMD 0.67%, and for the hip region, femoral neck BMD 1.41%, Ward's triangle BMD 2.34%, and trochanter 1.53%. These precision measures for DEXA scanning are also similar to those published.^{27,28}

The prevalence of osteoporosis was investigated from T-scores for BMD at different sites. The World Health Organisation (WHO) criteria were used to classify T-scores as normal (≤ 1 SD below young adult mean), osteopenic (1–2.5 SD below young adult mean), or osteoporotic (> 2.5 SD below young adult mean).²⁹

Independent *t*-tests (SPSS for Windows, v10.0) were used to test for significance between the groups for total body BMD and regional BMD and BMC, prevalence of osteoporosis, and to test for homogeneity between SCI and their controls. Independent *t*-tests were also used to detect any significant influence of level and completeness of injury (tetraplegics vs paraplegics, incomplete lesion vs complete lesion) on total body BMD and regional BMD and BMC. Arm BMD and BMC in the tetraplegic and paraplegic groups, and those spinal injured participants with incomplete and complete lesions was compared with the controls using independent *t*-tests. Pearson correlation coefficients were used to examine the relationship between activity levels, DOI, and total body and regional BMD values for the SCI group, and activity level influence for total body and regional BMD values for the control group. Statistical significance was accepted at $P < 0.05$.

Results

Characteristics of each group are shown in Table 1. As expected, the groups did not differ in age, height, weight, or BMI. Moreover, activity levels did not differ between the groups. The Pearson correlation coefficient for height in the control group (measured height vs electronic measurement) was 0.996 ($P = 0.0001$) con-

Table 1 Group characteristics for the spinal cord injured males and their matched able-bodied controls (mean $\pm$ SD)

Parameter	Spinal injured (n = 17)	Controls (n = 17)	Significance (P value)
Age (years)	32 $\pm$ 8	32 $\pm$ 10	0.9
Height (cm-electronic ruler)	180 $\pm$ 6	179 $\pm$ 6	0.4
Weight (kg)	73.9 $\pm$ 12.3	75.9 $\pm$ 6.6	0.6
BMI	22.8 $\pm$ 3.4	23.9 $\pm$ 1.9	0.2
Physical activity (mins)	442 $\pm$ 225	367 $\pm$ 167	0.3

firming the validity of the electronic measurement for all participants.

The mean duration of injury (DOI) for the SCI participants was 116 ± 83 months (range 7–372 months). Eleven participants were tetraplegic, with lesion levels involving C4–C7. Of these five participants were classified as Frankel A, five Frankel B and one Frankel C. The six paraplegic participants had spinal lesions between T5–L3, with three participants classified as Frankel A, one Frankel B, and two Frankel C. Thus nine of the 17 SCI participants had sustained incomplete spinal cord lesions while eight had complete spinal cord lesions. Thirteen of the 17 SCI participants were regional or national wheelchair sports representatives, ie elite sportsmen who represented their province (regional) or were representative sportsmen for New Zealand. Sports participation was reported in skiing, quad rugby, wheelchair basketball, karate, athletics, road training (pushing), and weight training. All control participants undertook regular exercise, with three of the 17 being elite sportsmen (representative athletes for their province). Sports participated in by the control group were running, rowing, cycling, and karate. Upper limb loading was achieved in 13 members of our control group through weight training, undertaken on average of twice per week.

Significant differences between the SCI and control groups were found for total body, leg, femoral neck, Wards triangle, and trochanter BMD (Figure 1). By contrast, no group difference was seen for arm BMD, 1.05 ± 0.10 vs 1.04 ± 0.08 g/cm², $P=0.7$ for the SCI and control groups, respectively. Lumbar spine BMD was also not significantly different between the patient and control groups, 1.27 ± 0.14 vs 1.29 ± 0.13 g/cm², $P=0.7$, respectively.

Bone mineral content (BMC) of the legs was significantly lower in the SCI group than in the controls, 867 ± 252 vs 1328 ± 140 g, $P=0.0001$, for the SCI participants and their controls, respectively.

Figure 1 Bone mineral density (BMD) for total body and regional sites for the spinal cord injured (SCI) males and controls (mean $\pm$ SD). Total body (TB), femoral neck (FN), Wards triangle (WT), trochanter (T), lumbar spine (LS). * $P=0.0001$, **not significant

However arm BMC for the SCI group, 503 ± 79 g did not differ from that of the controls, 509 ± 61 g, $P=0.8$.

By WHO criteria, the mean T-scores for the SCI group demonstrated that leg and trochanter BMD was in the osteoporotic range, with BMD of the femoral neck and Wards triangle being in the osteopenic range. The T-scores at the leg, femoral neck, Wards triangle and trochanter were all significantly different from the able-bodied control group (Figure 2). However mean arm BMD T-scores for the SCI group fell within the normal range at 0.8 ± 1.2 , and did not differ significantly from the controls, 0.7 ± 1.0 , $P=0.7$.

Of the 17 SCI participants, 13 (76%) had leg BMD that met WHO criteria for osteoporosis, one (6%) was osteopenic and three (18%) were normal. At the femoral neck, six (35%) SCI participants were osteoporotic, eight (47%) were osteopenic, and three (18%) normal. Four (23%) SCI were osteoporotic at Wards triangle, 10 (59%) were osteopenic and three (18%) were normal. The trochanteric BMD for nine (53%) of the 17 SCI participants was in the osteoporotic range, seven (41%) osteopenic, and one (6%) normal. Lumbar spine BMD for 14 (82%) SCI individuals was normal, with three (18%) classified as osteopenic. Fifteen (88%) of our SCI had normal arm BMD T-scores with two (12%) in the osteopenic range. All able-bodied controls met the WHO classification for normal BMD at all regional sites.

No significant differences were found between the tetraplegic ($n=11$) and paraplegic ($n=6$) groups for age, DOI, activity levels, total BMD or any of the regional BMD/BMC values. Arm BMD and BMC did not differ significantly between the tetraplegic and control group (BMD = 1.05 ± 0.11 vs 1.04 ± 0.08 g/cm², $P=0.7$; BMC = 487 ± 76 vs 509 ± 61 g, $P=0.4$, respectively). Significance was also not found for this regional measure between the paraplegic and control group (BMD = 1.04 ± 0.07 vs 1.04 ± 0.08 g/cm², $P=0.9$; BMC = 533 ± 83 vs 509 ± 61 g, $P=0.5$), respectively.

Figure 2 Bone mineral density (BMD) T-scores for regional BMD in the spinal cord injured (SCI) males and controls (mean $\pm$ SD). * $P=0.0001$, **not significant

No significant differences were detected for DOI, activity levels, total BMD or any regional BMD/BMC values between those SCI with incomplete ($n=9$) and complete ($n=8$) lesions. The extent of neurological involvement did not differ significantly for arm BMD and BMC in our SCI participants with incomplete lesions ($n=9$) when compared with the controls ($\text{BMD} = 1.07 \pm 0.10$ vs 1.04 ± 0.08 g/cm², $P=0.9$; $\text{BMC} = 535 \pm 76$ vs 509 ± 61 g, $P=0.9$), nor was significance reached when our SCI participants with complete lesions ($n=8$) were compared with the control group ($\text{BMD} = 1.02 \pm 0.09$ vs 1.04 ± 0.08 g/cm², $P=0.7$; $\text{BMC} = 468 \pm 70$ vs 509 ± 61 g, $P=0.1$), respectively.

There were no significant correlations found between activity levels, DOI and BMD of the total body or any regional site for the whole SCI group, and no significant correlation between activity levels and total or regional BMD for the able-bodied controls.

Discussion

No previous study that we are aware of, has carefully matched a group of male SCI individuals with able-bodied controls for age, height, and weight to compare bone mass. In addition our groups comprised highly active individuals with similar average weekly time commitments to sport participation of more than 7 h for our SCI group and over 6 h for our controls. While the control group contained only three participants who were elite regional sporting representatives, their average weekly sports participation was well in excess of the 2½ h average sport and exercise time for New Zealanders.³⁰ Our findings show that upper limb bone mass is well preserved in both groups but that significant demineralisation in the lower body is present in the SCI group compared with their able-bodied controls.

Exercise increases site-specific osteogenesis in able-bodied individuals,^{15–18} although this has not been clearly demonstrated in the SCI population. In the lower body, studies using functional electrically stimulated (FES) exercise have provided equivocal results for site-specific BMD changes at the lumbar spine and proximal tibia.^{21–25} With a greater reliance in the SCI population on the upper limbs to provide movement for activities of daily living and sports participation, it could be suggested that the arms in the SCI group would be subjected to greater site-specific loading, and thus increased osteogenesis, than the able-bodied control group. We found no evidence of osteopenia in either the SCI or the control group which is in agreement with the work of Dauty *et al*,¹³ but differs with the findings of Garland *et al*.⁶ It was notable that our SCI and control groups had mean BMD of the arms greater than that of the LUNAR database population norms. This finding is also contrary to those of Sabo *et al*³¹ who reported lower BMD values in the SCI group with respect to the reference population (QDR 2000 Hologic). The

differences between our findings and those of Garland *et al*⁶ and Sabo *et al*³¹ may be due to the level and extent of neurological involvement of the spinal cord injury, the activity levels of the SCI populations, the duration of injury or the method of scanning used, or the fact that both our groups undertook sport participation that resulted in loading of the upper limbs.

Several factors appear to have a major influence on bone mass in SCI individuals. The level of the lesion and thus the extent of impairment of motor and sensory function is one, with tetraplegics (impairment of arms, trunk and legs³²) being more likely to lose bone mass throughout the skeleton than paraplegics (lower body segment paralysis³²).^{5,6,13,14} In addition, bone mass loss may be greater in SCI individuals with complete lesions (absence of sensory or motor function below the neurological level, including the lowest sacral segment³²) than those SCI who sustain incomplete lesions (partial preservation of motor and/or sensory function below the neurological level, including the lowest sacral segment³²).^{5,6}

A significant difference in arm bone mass between tetraplegic and paraplegic SCI has been reported by others.^{5,6,13,14,33} We did not find any substantial difference in arm BMC and BMD between our two SCI groups, nor were there differences noted when each SCI group was compared with the control population. A contributing factor to our disparity with the aforementioned studies may have been the inability to detect any significant differences in arm bone mass between our SCI participants with incomplete and complete lesions. Nevertheless, our results are particularly noteworthy in that 65% of our patient population were tetraplegic and thus had a greater degree of neurological involvement. Our results support this view that intensive exercise regimes may indeed have a positive influence on upper limb bone mass in the SCI population.

Considerable evidence shows that the paralysis that ensues from a spinal cord injury results in significant skeletal demineralisation, with the greatest loss in the lower limbs and hip region.^{6,25,34–36} In our SCI group, BMC of the legs was 65%, and BMD 73% that of their able-bodied controls. Hip region BMD in our SCI group was 67, 66 and 63% that of the control group, for FN, WT and T, respectively. These figures are slightly lower than those found by BeDell *et al*²¹ and Szollar *et al*,³⁶ but do support the extent of bone loss at these sites in our SCI individuals.

No difference was found for leg BMC or BMD between the tetraplegic and paraplegic participants, nor was there any difference for BMD of the hip region. Our bone mass findings at these sites concur with those of others.^{6,13,14,37} This may attest to the homogeneity of the study populations. That is, demineralisation of the sublesional areas is consistent in SCI whether their lesions result in tetraplegia or paraplegia and are complete or incomplete, however the extent of the loss may vary. A direct comparison

with other studies is difficult in that different scanners have been used to ascertain BMC and/or BMD of the regional areas. Or it may be that paralysis and subsequent immobilisation is the predominant causative factor for sublesional bone mass loss in SCI individuals.

The DOI has also been shown to affect the degree of demineralisation of the lower limbs and hip region, with the greatest bone mass loss being seen within the first 2 years post injury, thereafter reaching a plateau or steady state at the reduced level.^{35,36} We found no influence of DOI on any bone mass measurement. However our SCI group average for DOI was approximately 10 years, suggesting a plateau at a reduced BMD for the lower limbs and hip region, had been reached.

While the level and extent of neurological involvement and paralysis clearly affect skeletal demineralisation of the lower limbs and hip, this trend is not seen at the lumbar spine. Lumbar spine BMD is usually well preserved in SCI individuals, and it is thought to be associated with direct loading of the spine in the seated position.^{34–36,38,39} Lumbar spine bone mineral density in our SCI group was 98% that of the control group. DOI may have a small initial effect on lumbar spine BMD with a bone mass plateau being reached at or above normal BMD values by 10–19 years post injury. Tetraplegics demonstrate an initial post injury loss before attaining a BMD plateau, whereas paraplegics do not show any initial loss.^{37,40} No significant differences have been found between tetraplegic and paraplegic SCI for BMD at the lumbar spine once this bone mass plateau has been reached.^{37,40} The BMD of the lumbar spine was similar for both the tetraplegics and paraplegics in our study, and concurs with findings by Szollar *et al*³⁷ but is contrary to those of Tsuzuku *et al*.¹⁴ The DOI of the two groups in the study by Tsuzuku *et al*¹⁴ and ours may explain this difference.

We also investigated the fracture risk status of our SCI participants. SCI have been known to fracture lower limb bones with seemingly insignificant provocation,^{41–43} with estimates of fracture incidence from as low as 1 to 9%^{42,43} to as high as 34%.⁴¹ The fracture risk in our group of SCI was identified using the WHO criteria, which estimates that each unit decrease (T-score) in BMD increases fracture risk by 1.5 to 3 times. Leg BMD T-scores suggest that the SCI group are five to 11 times more likely to suffer a fracture in this area than subjects with T-scores of zero. In a recent study by Lazo *et al*⁴¹ fracture risk at the femoral neck in SCI participants was estimated to be 2.8 times greater for each BMD T-score unit decrease. Thus our SCI group had a fracture risk at this site six times that of able-bodied controls. Although no fractures were reported by any of our participants at the time of their recruitment into the study, however fractures have occurred in two of our paraplegic participants since the data collection for this study was completed. Fractures to the femoral neck and femur as

a result of a skiing accident occurred in one participant, while fractures of the great toe, coccyx and ribs followed a fall in the other.

The present study supports the evidence to date that significant demineralisation of the skeleton occurs with paralysis, and that the lower limbs are most affected. What we have found, which disagrees somewhat with other studies, is preservation of arm bone mass in a group of SCI who undertake intensive physical activity. This finding seems especially significant in that the study population comprised a high proportion of tetraplegic participants, who have been reported to be 'at risk' for demineralisation in the upper limbs. Arm bone mass was preserved similarly in both the tetraplegic and paraplegic participants. The values at this site did not differ between our SCI and able-bodied control groups. Indeed the bone mass values in the arms of both SCI and control groups tended to be greater than the LUNAR reference population. Although significant demineralisation in the lower limbs in the SCI population may result in fractures, these do not usually impair normal activities of daily living. By contrast, SCI have a heavy reliance on the upper limbs for movement and activities of daily living. Thus BMD preservation in the arms is imperative. We suggest intensive exercise may help to preserve arm bone mass in SCI, although further research is required to investigate this hypothesis.

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