ACRM
AMERICAN CONGRESS OF REHABILITATION MEDICINE

Archives of Physical Medicine and Rehabilitation

journal homepage: www.archives-pmr.org

Archives of Physical Medicine and Rehabilitation 2014;95:2342-9

ORIGINAL ARTICLE

Bone Mass in Individuals With Chronic Spinal Cord Injury: Associations With Activity-Based Therapy, Neurologic and Functional Status, a Retrospective Study

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Abstract

Objective: To describe the prevalence of osteoporosis and its association with functional electrical stimulation (FES) use in individuals with spinal cord injury (SCI)-related paralysis.

Design: Retrospective cross-sectional evaluation.

Setting: Clinic.

Participants: Consecutive persons with SCI (N=364; 115 women, 249 men) aged between 18 and 80 years who underwent dual-energy x-ray absorptiometry (DXA) examinations.

Interventions: Not applicable.

Main Outcome Measure: Prevalence of osteoporosis defined as DXA T score ≤ -2.5.

Results: The prevalence of osteoporosis was 34.9% (n=127). Use of FES was associated with 31.2% prevalence of osteoporosis compared with 39.5% among persons not using FES. In multivariate adjusted logistic regression analysis, FES use was associated with 42% decreased odds of osteoporosis after adjusting for sex, age, body mass index, type and duration of injury, Lower Extremity Motor Scores, ambulation, previous bone fractures, and use of calcium, vitamin D, and anticonvulsant; (adjusted odds ratio [OR]=.58; 95% confidence interval [CI], .35−.99; P=.039). Duration of injury >1 year was associated with a 3-fold increase in odds of osteoporosis compared with individuals with injury <1 year; (adjusted OR=3.02; 95% CI, 1.60−5.68; P=.001).

Conclusions: FES cycling ergometry may be associated with a decreased loss of bone mass after paralysis. Further prospective examination of the role of FES in preserving bone mass will improve our understanding of this association.

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Low bone mass is a significant comorbidity associated with spinal cord injury (SCI)-related paralysis and is reported to be as high as 81%.[1] The clinical significance of low bone mass is related to the propensity to develop fractures, reported to be between 1% and 39%, depending on the extent of time since neurologic injury.[2-9] Fractures occurring in individuals with paralysis, especially persons who use wheelchairs as their primary means of mobility, are challenging because there is no commonly accepted standard of management. Some physicians opt to surgically stabilize the fractures, whereas others prefer conservative management. From a clinical perspective, both approaches have advantages and disadvantages; however, prevention of fractures in persons with SCI remains a more desirable clinical goal.

Activity and exercise are increasingly used as therapeutic interventions that can enhance day-to-day and neurologic function

Disclosures: none.

0003-9993/14/$36 - see front matter © 2014 by the American Congress of Rehabilitation Medicine
http://dx.doi.org/10.1016/j.apmr.2014.07.395

in individuals with chronic paralysis.[10-16] There are insufficient data to confirm that fractures occur more frequently when individuals with SCI-related paralysis participate in sustained exercise programs (eg, activity-based restorative programs). However, anecdotal experience still limits willingness of health care providers to recommend these types of programs to individuals with chronic paralysis. Identifying the individuals at risk of developing low bone mass and low impact fractures is warranted.

Functional electrical stimulation (FES), a component of activity-based restorative programs, is aimed at neuromuscular activation below the level of the lesion to promote functional recovery.[17,18] The principles of activity-dependent neural plasticity, driven by repetitive activation of the neuromuscular system above and below the level of injury, underlie the use of activity-based restorative programs to improve nervous and muscular system function.[17,18] FES and activity-based training have been used extensively in traumatic SCI rehabilitation programs.[19,20] FES was associated with reduced disability and improved voluntary grasping in a randomized trial of 24 subjects with SCI.[19] Activity-based therapy has been associated with improvement in ambulation in a prospective observational cohort of 196 persons.[20] Our group recently determined that among persons with chronic SCI, FES cycling is associated with improved neurologic and functional performance, reduced spasticity, increased muscle tone, and improvement in quality of life.[21]

Previous studies have shown that osteoporosis and bone mass loss in individuals with SCI-related paralysis depend on the injury level and severity,[22,23] time since injury,[7,24,25] and ambulatory status.[26] Reported findings from studies that examined the effect of different physical modalities interventions in preventing or reversing bone loss[27-32] suggest some benefit from ambulation, FES ergometry and electrical stimulation, standing, and other physical modalities (eg, pulsed electromagnetic fields, low-intensity ultrasound); however, no correlation to bone fracture rates has been established.

Pharmacologic approaches to bone mass loss prevention and restoration have yielded conflicting results in persons with SCI.[33-36] Bisphosphonate use appears to have the most potential for prevention of bone mass loss associated with paralysis, especially if used early after the injury.[37,38] In this study we set out to describe the characteristics of a cohort of individuals with SCI-related paralysis in relation to bone mass and to examine the association between activity (ambulation, FES-assisted ergometry) and osteoporosis prevalence in this population.

Methods

Participants

Data were collected (after approval was obtained from the institutional review board) through chart review of 364 consecutive adults between the ages of 18 and 80 years with paralysis who underwent dual-energy x-ray absorptiometry (DXA) examinations as part of their medical evaluation at the International Center for Spinal Cord Injury at Kennedy Krieger Institute in Baltimore, Maryland, between June 2005 and June 2009. Data collected included age, sex, level and severity of injury as per the ASIA Impairment Scale (AIS), time since injury, ambulatory status, FES usage, daily calcium and vitamin D intake, and anticonvulsant drug use. All individuals underwent neurologic and bone mass assessment by DXA as a part of their clinical evaluation. DXA was obtained in an interval that did not exceed 6 months after neurologic assessment.

List of abbreviations:

AIS	**ASIA Impairment Scale**
BMI	**body mass index**
CI	**confidence interval**
DXA	**dual-energy x-ray absorptiometry**
FES	**functional electrical stimulation**
LEMS	**Lower Extremity Motor Score**
OR	**odds ratio**
SCI	**spinal cord injury**

Outcome measure

The main outcome was osteoporosis, defined as having $\geq$1 region of interest on a DXA examination with a T score ≤ -2.5. When analyzing the hip, only the neck and total hip were used to diagnose osteoporosis. Diagnosis of osteoporosis was most frequently made on the basis of low DXA bone mass of either the right or left hip (total and/or neck area) and rarely on the basis of lumbar spine. We further defined categories of bone density as normative ($T \geq -1$); osteopenia ($-2.5 < T < -1$), and osteoporosis ($T \leq -2.5$).

Dual-energy x-ray absorptiometry

For 331 (90.1%) of the study participants, DXA examinations were performed as part of routine clinical evaluation for patients with paralysis at the International Center for Spinal Cord Injury using Hologic Discovery equipment and software.[a] In the other 33 (9.1%) participants, bone mass was assessed outside of the International Center for Spinal Cord Injury; therefore, the exact type of equipment used is not known. For individuals assessed at the International Center for Spinal Cord Injury, the regions of interest examined included the lumbar spine, bilateral hips, and bilateral forearms. For the 9.1% who underwent evaluations outside of the center, only the lumbar spine and left hip were assessed (standard of care for postmenopausal osteoporosis assessment). T scores (but not z scores) were used because individuals with bone mass assessed outside of our center only reported T scores.

Other measures

Level and severity of SCI

Neurologic level of injury was determined by physical examination using the AIS. Paraplegia was defined as the level of injury at or below the T1 level, and tetraplegia was defined as injury between C1 and C8 (inclusive). AIS grades A and B denote motor complete injuries, whereas AIS grades C and D represent motor incomplete injuries. The Lower Extremity Motor Score (LEMS) was defined as the sum of all 10 key muscle functions in bilateral lower limbs, with the maximum LEMS being 50. Because bone density loss in persons with SCI is dependent on time since injury,[7,24,25] we classified the duration of injury as $<$1, 1 to 5, and $>$5 years.

Functional electrical stimulation

FES ergometry was performed either at the International Center for Spinal Cord Injury or at the participants' home (for those that owned their own ergometer), using an RT 300-SL ergometer.[b] Through Bluetooth[c] technology, the RT 300 SL ergometer allows for electronic storage of performance data via the Internet; therefore, the amount of FES bicycling performed by each

participant was objectively recorded and stored in the International Center for Spinal Cord Injury database. At our center, lower-extremity FES stimulation is conducted by placing electrodes on the quadriceps, hamstring, and gluteal muscles bilaterally. Although each patient's parameters are set according to sensory deficits, the general stimulation algorithm to induce bilateral reciprocal leg cycling motion includes a maximal electrical intensity of 140mA, 500μs pulse width, 30 to 40Hz frequency, with a target goal of 50 revolutions per minute. The duration of FES use ranges from 30 to 60 minutes per session.

Pharmacologic agents

We obtained the use of pharmacologic agents (eg, anticonvulsants, calcium, vitamin D supplementation) from medical charts. Because each patient's therapeutic dose is dependent on the presenting characteristics and need, we report history of the use of pharmacologic agents with the supposition that patients were on therapeutic doses identified to be appropriate by the patient's treating physician.

Statistical analysis

We compared population characteristics among persons by DXA T score category (normative [$T \geq -1$]; osteopenia [$-2.5 < T < -1$]; osteoporosis [$T \leq -2.5$]) using descriptive statistics. Univariate and multiple logistic regression models were fit to examine the association between osteoporosis and factors that are known to potentially influence bone mass. Potential confounders adjusted for in multivariate analysis include FES use; sex; age; body mass index (BMI); ambulation (use of ambulation as the primary means

Table 1 Baseline demographic and clinical characteristics of study participants with SCI (N=364)

Characteristic	Total	Normative (T≥−1.0; n=67)	Osteopenia (−2.5<T<−1; n=170)	Osteoporosis (T≤−2.5; n=127)
Male	249 (68.4)	52 (77.6)	111 (65.3)	86 (67.7)
Female	115 (31.6)	15 (22.4)	59 (34.7)	41 (32.3)
Age (y)	39.8±16.1	40.3±16.7	37.6±15.9	42.3±15.8*
Type of injury				
Traumatic	276 (75.8)	49 (73.1)	134 (78.8)	93 (73.2)
Nontraumatic	88 (24.2)	18 (26.9)	36 (21.2)	34 (26.8)
Injury level				
Paraplegia	170 (46.7)	37 (55.2)	76 (44.7)	57 (44.9)
Tetraplegia	194 (53.3)	30 (44.8)	94 (55.3)	70 (55.1)
Ambulatory	79 (21.7)	17 (25.4)	44 (25.9)†	18 (14.2)
FES use	202 (55.5)	39 (58.2)	100 (58.8)	63 (49.6)
Injury duration (y)				
≤1	109±30.0	29±43.3	58±34.1†	22±17.3
1−5	130±35.7	22±32.8	59±34.7†	49±38.6‡
>5	125±34.3	16±23.9	53±31.2†	56±44.1‡
AIS grade				
Motor complete (grades A and B)	178 (49.2)	31 (47.0)	81 (47.9)	66 (52.0)
Motor incomplete (grades C or D)	184 (50.8)	35 (53.0)	88 (52.1)	61 (48.0)
LEMS§	2.0 (0−21.0)	2.0 (0−21.0)	2.5 (0−27.0)	0 (0−15.0)
LEMS category				
<10	233 (64.0)	45 (67.2)	102 (60.0)	86 (67.7)
≥10	131 (36.0)	22 (33.3)	68 (40.5)	40 (32.3)
TMS	49.1±24.7	50.1±26.0	51.5±25.2	45.3±23.0
Previous fractures	74 (30.3)	11 (16.7)	32 (18.7)	31 (24.4)
BMI	24.6±5.3	25.8±5.3	24.8±5.0	23.9±5.6
BMI categories				
<18.5	34 (9.5)	6 (9.2)	13 (7.7)	15 (12.0)
18.5−24.9	166 (46.2)	22 (33.9)	79 (46.8)	65 (52.0)
>25	159 (44.3)	37 (56.9)	77 (45.6)	45 (36.0)
Calcium use	155 (43.1)	27 (40.9)	69 (41.1)	59 (46.8)
Anticonvulsant use‖	112 (30.9)	19 (28.8)	59 (34.9)	34 (26.8)
Vitamin D use	157 (43.6)	29 (43.9)	68 (40.2)	60 (48.0)

NOTE. Values are mean ± SD, n (%), or as otherwise indicated.
Abbreviation: TMS, total motor score.
* $P<.05$, osteoporosis versus osteopenia.
† $P<.05$ compared with normative and osteoporosis.
‡ $P<.05$, osteoporosis versus normative.
§ Value is presented as median (interquartile range).
‖ Anticonvulsive therapy includes gabapentin, phenytoin, and topiramate.

of household and community mobility, defined as ambulating >45m without rest); type, severity, and duration of injury; LEMS; history of bone fractures; calcium supplement use; multivitamin (including vitamin D) use; and use of anticonvulsant therapy. Because a LEMS ≥10 is associated with ambulation, we further dichotomized the LEMS at this point and assessed the association with osteoporosis. We examined for interactions between LEMS, paraplegia/tetraplegia, and ambulation and checked for collinearity by estimating the variance inflation factor. To examine the joint hypothesis that the coefficients of the interactions were zero, we performed a Wald test. Because of altered mechanical impact of the radius in persons with paraplegia or tetraplegia, we compared radius bone mass by injury. We also performed sex-stratified analyses to examine the outcome separately among men and women, and sensitivity analyses excluding persons with paraplegia who presented with lower motor neuron or flaccid paralysis. Statistical analyses were performed (by E.R.H.) using Stata Statistical Software release 10.[d]

Results

A total of 115 women and 249 men with SCI were included in this analysis. The mean age at injury was 39.8±16.1 years. The average injury duration was 6.9 years (interquartile range, 1−8y), with 46.7% of injuries resulting in paraplegia and 53.3% in tetraplegia (table 1). A total of 12 (7.1%) of 170 participants with paraplegia presented with lower motor neuron lesions. Cervical injuries accounted for 53.3% (n=194) of injuries, 42.6% (n=155) were thoracic injuries, and 4.1% (n=15) were lumbar injuries. Traumatic SCI accounted for 276 (75.8%) injuries, with 21.7% of participants ambulating functionally. A total of 109 individuals (30%) had SCI <1 year old, whereas 130 individuals (35.7%) had SCI between 1 and 5 years old. In 125 individuals (34.3%), SCI was >5 years old.

The overall prevalence of osteoporosis in individuals with SCI-related paralysis was 34.9% (n=127). Osteopenia (defined as a T score between >−1 and −2.4) was present in 46.7% (n=170) of participants, and bone mineral density was normative in only 18.4% (n=67). Utilization of the lumbar spine as the sole area to establish an osteoporosis diagnosis was, as expected in this population, the least sensitive (n=11). Diagnosis using the lumbar spine and left hip regions of interest captured only 96 of 127 cases of osteoporosis, a sensitivity of 75.6%.

The use of FES in persons with SCI was associated with a 31.2% prevalence of osteoporosis compared with 39.5% when FES was not used (fig 1). We present unadjusted odds ratios (ORs) for the association between FES use and osteoporosis in table 2. In multivariate-adjusted analyses, there was a 42% decrease in odds of having osteoporosis in individuals performing FES (OR=.58; 95% confidence interval [CI], .35−.99; P=.039), after adjusting for sex, age, BMI, type and duration of injury, LEMS, ambulation, previous bone fractures, calcium, multivitamin, and anticonvulsant use (table 3).

Ambulation was also associated with decreased odds of having osteoporosis (OR=.48; 95% CI, .27−.85; P=.012) in unadjusted analysis. However in adjusted analysis, this observed association was not significant (OR=.48; 95% CI, .19−1.2; P=.117). Similarly, the decreased odds of having osteoporosis associated with LEMS (continuous or per 10-point increase) observed in unadjusted analysis was not statistically significant in adjusted analysis. Persons with LEMS ≥10 did not have increased odds of osteoporosis compared to those with LEMS <10, adjusted OR=.81 (95% CI, .42, 1.56); P=.539.

Compared with persons with a healthy BMI, those with a BMI between 25 and 40 were observed to have a 58% decreased odds of osteoporosis in adjusted analysis (OR=.42; 95% CI, .24−.73; P=.002). Time since injury of >1 year was associated with at least a 3-fold increase in odds of osteoporosis compared with SCI sustained within a year (see table 3).

Type and severity of injury, calcium and vitamin D intake, use of anticonvulsant therapy, and previous bone fractures were not associated with likelihood of having osteoporosis. Although we observed increasing odds of having osteoporosis with increasing age category, these associations remained nonsignificant in adjusted analysis. In analysis stratified by sex and age there was no association between FES use and osteoporosis. When we excluded persons with paraplegia who had flaccid paralysis from the analysis, there were no significant changes to the observed associations. There was no difference in the bone density of the radius among persons with paraplegia and tetraplegia. Table 4 shows parameters of FES use among study participants.

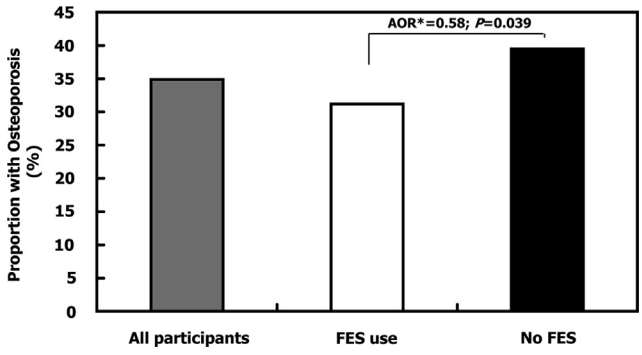

Fig 1 Proportion with osteoporosis (bone mineral density T score ≤−2.5) by FES use among persons with SCI. Abbreviation: AOR, adjusted odds ratio. *AOR for the association between FES use and osteoporosis (T score ≤−2.5) (AOR=.59; 95% CI, .35−.99; P=.046). OR is adjusted for sex, age, ambulation, type and duration of injury, LEMS, history of bone fractures, calcium supplement use, vitamin D use, and anticonvulsant therapy use.

Discussion

Our findings suggest an association between a decreased prevalence of osteoporosis diagnosed by DXA examination among FES users with SCI-related paralysis. FES use was associated with a 42% decreased odds of osteoporosis. The prevalence of osteoporosis was 34.9%, in contrast with other studies that have prevalence as high as 81.5%.[25] Risk factors that are commonly associated with osteoporosis (eg, sex, age) were not determined to be significantly associated with osteoporosis in this cohort. Our findings may be the result of a lower proportion of women in our population and a smaller number of persons in older age groups. We did not observe increased prevalence of osteoporosis among persons with paraplegia compared with persons with tetraplegia or among persons with LEMS <10 compared with LEMS ≥10. There is evidence to suggest that persons with paraplegia can lose bone mass at a rapid rate with neurogenic factors believed to influence osteoporosis during paralysis irrespective of the neurologic level of injury.[39,40] The sympathetic regulation of bone in humans is believed to play a role in bone density after SCI.

Table 2 Unadjusted OR showing the association between FES use and osteoporosis in persons with SCI using logistic regression

Covariate	Unadjusted OR	95% CI	*P*
FES use	0.69	0.45–1.08	.099
Male sex	1.05	0.66–1.67	.836
Age categories			
18–25y	1.00 (ref)	NA	NA
25–49y	1.59	0.92–2.73	.096
50–80y	1.76	0.97–3.20	.065
Ambulatory	0.48	0.27–0.85	.012
LEMS, continuous	0.99	0.97–1.00	.042
LEMS, per 10-point increase	0.86	0.75–0.99	.042
Total Motor Score, continuous	0.99	0.98–1.00	.032
Total Motor Score, per 10-point increase	0.91	0.83–0.99	.032
Traumatic injury	1.24	0.75–2.03	.398
Paraplegia	0.89	0.58–1.38	.610
Injury duration			
≤1	1.00 (ref)	NA	NA
1–5	2.39	1.33–4.30	.004
5	3.21	1.79–5.76	<.001
BMI category			
18.5–24.9	1.00 (ref)	NA	NA
<18.5	1.23	0.58–2.58	.591
25.0–40.0	0.61	0.37–0.98	.039
Previous bone fractures	1.45	0.86–2.44	.164
Calcium use	1.27	0.82–1.96	.290
Vitamin D use	1.31	0.85–2.03	.221
Anticonvulsant use	0.74	0.46–1.19	.208
AIS grade		NA	NA
Motor complete (grades A and B)	1.00 (ref)	NA	NA
Motor incomplete (grades C and D)	0.84	0.55–1.30	.434

Abbreviations: NA, not applicable; ref, reference.

Table 3 Adjusted OR showing the association between FES use and osteoporosis (T≤−2.5) in persons with SCI

Variable	Adjusted OR	95% CI	*P*
FES use	0.58	0.35–0.99	.039
Male sex	1.00	0.57–1.73	.989
Ambulatory	0.48	0.19–1.20	.117
LEMS, per 10 points	0.83	0.65–1.06	.136
Age (y)			
18–25	1.00 (ref)	NA	NA
25–49	1.88	0.97–3.64	.063
50–80	2.05	0.92–4.57	.079
BMI category			
18.5–24.9	1.00	NA	NA
<18.5	1.09	0.47–2.52	.845
25.0–40.0	0.42	0.24–0.73	.002
Traumatic injury	1.81	0.98–3.35	.058
Incomplete motor injury	1.64	0.58–4.61	.350
Injury duration (y)			
≤1	1.00 (ref)	NA	NA
1–5	3.02	1.60–5.68	.001
5	3.56	1.78–7.11	<.001
Previous bone fractures	1.29	0.70–2.37	.418
Calcium use	1.38	0.61–3.14	.439
Vitamin D use	0.87	0.38–1.98	.739
Anticonvulsant use	0.81	0.46–1.42	.474

Abbreviations: NA, not applicable; ref, reference.

The mechanism of bone loss in individuals with paralysis is unclear and appears to be multifactorial. Potential contributors to development of osteoporosis and low bone mass in individuals with SCI-related paralysis include inactivity and disuse or lack of load on weight-bearing bones,[41] rapid bone resorption (osteoclast activity) or decreased bone deposition (osteoblast activity),[42] decreased osteocyte formation,[43] increased expression of substance P in sublesional bone,[44] and decreased circulating osteoprotegerin.[45]

No one single neural factor is responsible for bone loss, but a multitude of factors make bone loss a significant paralysis-related comorbidity. Low bone mass in itself may not be the major issue; however, bone fractures contribute to increased morbidity in individuals with SCI-related paralysis by increasing immobility, further decreasing performance of independent activities of daily living and increasing incidence of other complications (heterotopic ossification, decreased range of motion with troubles positioning or performing mobility tasks, prolonged bed rest leading to increased muscle atrophy, pressure ulcerations, pain, autonomic dysreflexia, progressive deconditioning).[31,46] Time since the onset of neurologic injury has a very strong correlation with bone mass loss. Our finding that bone mineral density rapidly decreases and often leads to development of osteoporosis after the first year after injury is similar to reports from previous studies.[47,48] The rapid bone loss occurring immediately after injury poses a challenge to medical and physical rehabilitation professionals. No treatment to date is consistently effective in preventing or restoring bone loss and preventing fractures in individuals with SCI-related paralysis. Therefore, it may be more effective to minimize early bone loss by applying quick and efficient preventive interventions to all individuals with new onset paralysis seen in the acute medical setting, rather than attempting to initiate a sustained bone building intervention in the chronic stage of paralysis, which would invariably reach only a limited number of the population at risk and be subjected to higher costs and lower compliance.

Multivariate analysis adjusted for FES use attenuated the observed protective association offered by weight bearing and ambulation against bone mass loss in SCI, which was observed in univariate analysis. Attributing paralysis-related bone mass loss to immobilization alone may negate the effect of the neural factor that appears to play an important role. Our findings suggest that a combination of FES-assisted ergometery, gait training/weight loading, and ambulation may be more beneficial in preventing bone loss. The decision to participate in a rehabilitation program needs to be evaluated carefully with clinician judgment for the risk of potential bone fractures and falls to derive the best benefit to maintain or improve bone mass. To ensure safety and minimize fracture occurrence, objective criteria that can predict fracture risks in this specific population need to be developed, along with guidelines that minimize injury while promoting active weight bearing, FES ergometry, and maintenance of bone mass.

Study limitations

Some limitations need to be considered in interpreting our findings. Information about FES activity was collected through

Table 4 Characteristics of FES use among study participants with SCI (n=173)

Characteristic	Total	Normative (T*≥−1; n=36)	Osteopenia (−2.5<T<−1; n=84)	Osteoporosis (T≤−2.5; n=53)
Duration (wk)	20.2 (1.0—24.0)	16.1 (1.0—23.0)	21.0 (1.0—24.0)	21.7 (1.0—26.0)
Sessions per week	2.3 (1.0—3.0)	2.7 (1.03—4.0)	2.3 (1.0—3.0)	1.9 (0.8—3.0)
Leg sessions	27.0 (3.0—21)	30.7 (3.0—28.5)	30.8 (2.5—20.5)	18.5 (3.0—13.0)
Average distance, units (IQR) (km)	8.1 (4.7—10.5)	8.1 (5.5—9.5)	8.5 (4.8—10.9)	4.5 (2.6—6.1)
Average energy per hour (kJ/h)	61,412.8 (25,769.3—60,270.5)	51,597.1 (22,459.7—74,441.7)	69,073.7 (31,493.0—75,826.6)†	55,935.9 (24,292.3—54,249.7)
Average stimulation level (% range 0—100)	83.2 (76.4—99.0)	87.5 (83.3—98.9)	78.8 (65.7—98.3)	87.3 (82.0—99.2)
Average charge level (microcoulombs)	28.8 (17.5—34.7)	32.9 (27.2—36.4)	26.6 (17.1—34.0)	29.5 (14.5—34.7)

Abbreviation: IQR, interquartile range.
NOTE. Values are mean (interquartile range) or as otherwise indicated.
* T score for bone mineral density measurement.
† $P<.05$.

clinical interview in 173 (85.6%) of 202 FES users and confirmed by accessing each individual's electronically collected FES performance information stored on a secure server at the headquarters of Restorative Therapies using Bluetooth technology. For the 29 (14.3%) individuals that did not use the FES RT 300-SL ergometer, we were only able to use the self-reported amount of ergometer usage per week. Consequently, we reported the amount of FES activity expressed as distance, total amount of sessions, or amount of work for 173 participants. We were also unable to evaluate the association between particular dimensions of FES use (eg, level of stimulation, intensity, energy expended) and bone mass because of the small number of participants in these subgroups.

Typical DXA bone mass assessment performed clinically analyzes only the bone in the lumbar spine (L1-4) and 1 hip (usually the left one). In this study, for 90.1% of the participants (the ones undergoing DXA bone mass analysis at the International Center for Spinal Cord Injury), we measured the bone mass in the lumbar spine (L1-4), bilateral hips, and bilateral wrists. We postulated that measuring bone mass at all 3 sites would increase the number of participants diagnosed as having osteoporosis. Indeed, if only the left hip and lumbar spine had been analyzed, 31 (24%) of 127 individuals ultimately diagnosed as having osteoporosis would have been misclassified as having normative bone density.

We did not use the knee, a well-recognized site of bone loss in individuals with paralysis, for assessing bone mass because the DXA technique for periknee bone mass assessment is not standardized in clinical practice, and there are no correlates between periknee bone mass and likelihood of fracture development. We also proposed to use DXA testing that is easily available for each practitioner in their own setting of clinical practice; therefore, interpretation of our results is directly applicable to their experience.

We report bone mass (and diagnosis of osteoporosis) as a function of a T score because we used DXA bone mass reports generated from the International Center for Spinal Cord Injury and outside institutions. For participants in this study between 18 and 50 years old, a more accurate assessment of bone mass would use z scores with classification as low or normative based on their chronological age. However, we were unable to use z scores because DXA scans performed at institutions other than ours reported only T scores.

It has been documented that osteoporosis and fragility fractures are significant complications after SCI-related paralysis.[31,32] Our findings, similar to other studies, suggest a rapid decline in bone mineral density after the first year of injury, after accounting for sex, age, BMI, level and severity of injury, LEMS, ambulation, previous bone fractures, and calcium, multivitamin/vitamin D, and anticonvulsant use. We were, however, unable to assess therapeutic doses and duration of use of pharmacologic supplements. Future efforts may include this information to better evaluate their effects on bone density in persons with SCI. The bone loss that occurs early after the injury, independent of whether ambulation is preserved, may suggest the importance of identifying methods to prevent bone loss immediately after the onset of neurologic injury and routinely monitoring bone health in individuals with paralysis.

Conclusions

Our findings have relevance in persons with limited mobility resulting from neurologic disease. This article includes a breadth of parameters related to FES use and functional status, which enhance the understanding of the prevalence and distribution of bone density among persons with SCI.

Future research needs to focus on establishing standardized guidelines regarding bone mass assessment in persons with SCI or other neurologic conditions that cause paralysis and identifying effective treatment interventions in this population at high risk for bone mass loss. Lower-limb FES cycle ergometry when used early following SCI may minimize bone mass loss and prevent the onset of osteoporosis.

Suppliers

a. Hologic Inc, 250 Campus Dr, Marlborough, MA 01752.
b. Restorative Therapies, 1434 Fleet St, Baltimore, MD 21133.
c. Bluetooth SIG, 5209 Lake Washington Blvd NE, Ste 350, Kirkland, WA 98033.
d. StataCorp, 4905 Lakeway Dr, College Station, TX 77845-4512.

Keywords

Osteoporosis; Paralysis; Rehabilitation; Spinal cord injuries

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Acknowledgments

We thank Shannon Inches and Thierry Houdayer, MS BME, who assisted with data collection and data management for this research project.

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