Bone Mineral Density of the Hip and Knee in Children With Spinal Cord Injury

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Received October 25, 2006; accepted February 12, 2007

Abstract

Background/Objective: To report on the bone mineral density (BMD) of the hip, distal femur, and proximal tibia in children with spinal cord injury (SCI) of at least 1-year duration and before skeletal maturity.

Methods: BMD values were measured in 28 children (age, 9.6 ± 2.5 years; range, 5–13 years) using dual-energy x-ray absorptiometry (DEXA) and were analyzed based on sex, injury, and time since injury. The hip values were compared with reported age- and sex-matched values in children without disability. No comparison was made at the knee because normative data were not available.

Results: Average BMD values were 0.48 ± 0.17 g/cm² for the total hip, 0.48 ± 0.17 g/cm² at the femoral neck, 0.41 ± 0.17 g/cm² at the greater trochanter, 0.47 ± 0.17 g/cm² at Ward's triangle, 0.38 ± 0.10 g/cm² at the distal femur, and 0.37 ± 0.07 g/cm² at the proximal tibia. Trends were observed with respect to sex, level of injury, and time since injury. Z-scores for the femoral neck, greater trochanter, and Ward's triangle were -1.65 ± 1.02 , -1.83 ± 1.30 , and -1.78 ± 0.78 , respectively, representing a 40% lower BMD in comparison with children without disability.

Conclusions: Children with a SCI seem to have a substantially lower BMD at the hip and knee in comparison with children without disability, placing them at the same risk for lower extremity fractures as adults with SCI, with potentially higher risks as they age given the lack of activity in a period of their life where exercise is essential for optimal bone health.

J Spinal Cord Med. 2007;30:S10–S14

Key Words: Spinal cord injury; Pediatrics; Bone mineral density; Fractures; Dual-energy x-ray absorptiometry

INTRODUCTION

The loss of mobility as a result of a spinal cord injury (SCI) leads to secondary complications that affect muscle, bone, and cardiovascular health. After SCI, there is an uncoupling between the rates of bone formation and reabsorption and a loss of muscle and gravitational stresses, which leads to reduced bone mass. This process starts almost immediately after SCI in adults, with a majority of the bone mineral density (BMD) being lost from 6 months to 2 years after the injury (1,2), and with continuing slow declines in BMD thereafter (3). As a result, adults with SCI have a greatly reduced BMD of the femoral neck, Ward's triangle, and greater trochanter, with values that are 50% to 60% of those of their able-

bodied peers (4–6). Losses of bone mass at the knee are also substantial, with reports of a BMD decline of 27% at the distal femur and 32% at the proximal tibia for men with SCI (7) and a 38% to 47% decline at the knee for women with SCI (8). This corresponds to a 4-fold increase in the risk of lower limb fractures (9).

Although the effects of SCI on BMD in the lower extremity have been studied extensively in adults, the same does not hold true for children with SCI. The effects of SCI on bone mass in children is of particular interest because, not only is there the potential of bone loss because of the same mechanisms as observed in adults with SCI, but there is also a lack of activity in a period of their life where exercise is essential for optimal bone health (10). For example, in a recent review of the literature, Hind and Burrows (11) identified 22 studies in which the effects of exercise of various types and intensities on bone mineral accrual in healthy children and adolescents were examined. In all cases, there was

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bone mineral accrual that was enhanced by exercise, particularly during early puberty. Thus, a lack of activity during this same period of development can be expected to have an equally large, but detrimental, effect (10).

The understanding of the effect of pediatric SCI on BMD could be beneficial to aid treatment at the stage of development when the skeleton is still growing to prevent long-term complications (12). Only 1 study has been identified in which hip BMD in children with SCI was directly measured (13). However, the study did not include any measurement around the knee, which is the site of a majority of lower limb fractures sustained by individuals with SCI (14,15), and thus, a region of interest for intervention. The purpose of this study, therefore, was to report on the BMD of the hip and the knee in children with a SCI of at least 1-year duration and that occurred before skeletal maturity.

METHODS

Subjects

A university-affiliated institutional review board approved this study, which was part of a larger study to examine the effects of functional electrical stimulation (FES) lower extremity cycling in children with SCI. All subjects were recruited from the existing pediatric patient population at Shriners Hospitals for Children, Philadelphia, PA. This study was registered with the National Institutes of Health public access database. Written informed consent from each subject's parents, along with verbal or written assent from each subject, was obtained before participation. The inclusion criteria for the subjects with SCI were (a) 12 months after injury, (b) cervical or thoracic level SCI with an American Spinal Injury Association (ASIA) A or ASIA B classification, (c) between the ages of 5 and 13 years, and (d) innervated lower extremity muscles. Exclusion criteria were (a) conditions (eg, arthritis) requiring chronic steroid treatment, (b) history of lower limb stress fractures, (c) heterotopic ossification of joints in the lower limbs, and (d) hip instability/dislocation. Demographics on the recruited subjects are presented in Table 1.

Dual-Energy X-Ray Absorptiometry Protocol

Dual-energy x-ray absorptiometry (DEXA; Delphi W; Hologic, Bedford, MA) was used to measure BMD (g/cm^2) at the left hip (total hip, femoral neck, greater trochanter, and Ward's triangle), distal femur, and proximal tibia, with the subject in the supine position. All scans were performed at an affiliated university hospital. The percent error per anatomical site at this institution for the pediatric population has not been established because children represented a small fraction of their overall clinical population. All scans were performed by 2 certified radiation technicians and checked for accuracy by a radiologist. During the test, the hip was positioned in neutral rotation, and the distal femur and proximal tibia were aligned so that the fan

beam of the scan was parallel to the long axis of each segment. Only the left hip and knee were scanned to reduce testing time and radiation exposure.

The technicians identified the regions of interest for the hip and knee, and the analytic software accompanying the system automatically performed the BMD calculations. No algorithm was available in the software for analysis of the distal femur and proximal tibia; therefore, the lumbar spine algorithm for examining the knee that was described by Shields et al (14) was used. This algorithm has been validated in adults with SCI, with a reported high reliability in knee measurement (Interclass Correlation Coefficient [ICC] = 0.98). Briefly, the lumbar spine algorithm was used to separately scan the distal femur and the proximal tibia. For the distal femur, the distal edge of the first region of interest was proximal to the lateral femoral epicondyle, with the remaining 3 regions extending proximally and all set to equal height. The global area was set just wide enough to include the entire femur with as little air space as possible. The lumbar spine algorithm was run, with manual image correction to include all the appropriate bone pixels as necessary. The same protocol was followed for the tibia, except that the edge of the first region of interest was placed just distal to the tibial plateau.

Data Analysis

Analysis of the data was performed through examination of the BMD values for the different regions and calculation of a Z-score where normative data were available. The BMD values for the participants were organized by sex, level of injury (cervical or thoracic), and time since injury (<2 and >2 years after injury) to examine for trends. No statistical analysis was performed, given the small sample size.

The calculation of the Z-score involved subtracting the average BMD value for the children of typical development, matched according to age and sex, from the value recorded for the child with SCI, and dividing the value by the SD of the typically developing group. The Z-score thus removes the potential confounders of age and sex bias to the data. The scores were calculated for the selected regions of the hip using the normative data base reported by Zanchetta et al (16) for children without disability in the same age range. No such calculation could be made for the total hip, distal femur, or proximal tibia because these values are unavailable for children with typical development.

RESULTS

Seventeen boys and 11 girls (age, 9.6 ± 2.5 years; range, 5–13 years) with chronic SCI (4.5 ± 2.9 years after injury) participated in this study. Twenty-five children were classified as ASIA A (motor and sensory complete), and 3 children were classified as ASIA B (motor complete and sensory incomplete). Table 1 lists the individual BMD values for each subject in the regions examined in this

Table 1. Raw BMD Values for All the Subjects in the Study

Subject	Age (years)	Time Since Injury	Sex	Level of Injury (ASIA)	Total Hip (g/cm ²)	Femoral Neck (g/cm ²)	Greater Trochanter (g/cm ²)	Ward's Triangle (g/cm ²)	Distal Femur (g/cm ²)	Proximal Tibia (g/cm ²)
1	5	4	F	C7-C8	0.126	0.172	0.125	0.159	0.347	0.305
2	5	4.5	M	T10	0.483	0.431	0.43	0.429	0.251	0.276
3	6	1	F	T7-T8	0.413	0.477	0.453	0.39	0.33	0.383
4	7	1.5	M	T7-T8	0.435	0.49	0.248	0.317	0.305	0.279
5	7	3.5	M	T3	0.615	0.441	0.331	0.491	0.372	0.358
6	7	4.5	F	T4-T6	0.163	0.171	0.229	0.209	0.264	0.318
7	7	5	M	T1	0.453	0.614	0.416	0.589	0.383	0.371
8	8	3.5	M	T1	0.664	0.653	0.709	0.635	0.451	0.415
9	8	5.5	M	C7	0.563	0.186	0.55	0.689	0.488	0.449
10	8	6.5	M	C8	0.191	0.42	0.744	0.362	0.341	0.399
11	8	8	M	T5	0.280	0.559	0.497	0.626	0.439	0.357
12	9	1	M	T4-T5	0.496	0.595	0.424	0.553	0.465	0.391
13	9	6	F	C7	0.570	0.257	0.147	0.196	0.243	0.225
14	10	5	F	T4-T5	0.762	0.422	0.289	0.423	0.312	0.345
15	11	5.5	M	T1-T2	0.394	0.391	0.326	0.403	0.313	0.283
16	11	6	F	T5	0.417	0.539	0.38	0.555	0.29	0.322
17	11	6.5	F	C8	0.583	0.684	0.493	0.475	0.519	0.471
18	11	7	M	T11	0.611	0.502	0.551	0.521	0.407	0.348
19	11	8	M	C7	0.527	0.138	0.089	0.123	0.181	0.354
20	12	1	F	T4	0.145	0.580	0.392	0.549	0.598	0.477
21	12	1	F	T1	0.524	0.601	0.599	0.861	0.430	0.459
22	12	2	F	T11	0.479	0.616	0.582	0.517	0.561	0.465
23	12	2	F	C7	0.653	0.752	0.256	0.426	0.348	0.285
24	12	2	M	T5	0.614	0.532	0.446	0.348	0.421	0.408
25	12	8	M	T7	0.580	0.567	0.53	0.556	0.451	0.511
26	12	12	M	C7	0.616	0.462	0.476	0.587	0.337	0.36
27	13	1	M	T5	0.458	0.458	0.289	0.530	0.468	0.411
28	13	7	M	T4	0.601	0.694	0.527	0.645	0.435	0.461

study. For the group as a whole, BMD values at the hip were 0.48 ± 0.17 g/cm², 0.41 ± 0.17 g/cm², and 0.47 ± 0.17 g/cm² for femoral neck, greater trochanter, and Ward's triangle, respectively. Total hip BMD was 0.48 ± 0.17 g/cm². At the knee, BMD values were 0.38 ± 0.10 and 0.37 ± 0.07 g/cm² for the distal femur and proximal tibia, respectively. In the regions where the Z-scores could be calculated, values were -1.65 ± 1.02 , -1.83 ± 1.30 , and -1.78 ± 0.78 for the femoral neck, greater trochanter, and Ward's triangle, respectively, representing an overall BMD that was 64.4%, 64.2%, and 57.8% of age- and sex-matched normative values. Again, no Z-score could be calculated for the knee regions because normative data in children were not available.

Table 2 lists the BMD values for the subjects grouped according to sex and level of injury, whereas Table 3 lists the BMD values based on time since injury. Given the large variations and small sample size, no statistical tests were performed; however, trends were observed. Higher BMD values were observed for individuals with a thoracic level injury in comparison with individuals with a cervical

level injury within-sex, and higher BMD values for boys compared with girls. There was also a time effect, with lower BMD values for individuals with an injury of greater than 2-year duration compared with individuals with an injury of less than 2-year duration.

DISCUSSION

This study is only the second study to report on BMD in children with SCI and the first to provide information about BMD values at the knee. Because these data were collected as part of a study to examine the effects of FES cycling on improving the health and fitness of children with SCI, there are certain limitations to the data. First, Tanner stage data were not collected; therefore, children could only be matched based on age. Also, because we were most interested in the effects of FES cycling on BMD change at the hip and knee, no scans were performed of the lumbar spine, and no values were recorded for bone mineral content (BMC) or bone area. Finally, all subjects that were examined here were selected as meeting the criteria for a study on FES lower extremity cycling. As

Table 2. BMD Values Averaged Across Regions for All the Subjects in the Study and Categorized According to Sex and Level of Injury

	Male, Cervical (n = 4)	Male, Thoracic (n = 13)	Female, Cervical (n = 7)	Female, Thoracic (n = 4)
Total hip	0.353 ± 0.227	0.526 ± 0.087	0.460 ± 0.294	0.476 ± 0.159
Femoral neck	0.302 ± 0.163	0.531 ± 0.087	0.466 ± 0.294	0.499 ± 0.179
Greater trochanter	0.465 ± 0.275	0.440 ± 0.126	0.255 ± 0.169	0.418 ± 0.139
Ward's triangle	0.440 ± 0.275	0.511 ± 0.108	0.314 ± 0.160	0.501 ± 0.199
Distal femur	0.337 ± 0.125	0.397 ± 0.069	0.364 ± 0.114	0.398 ± 0.135
Proximal tibia	0.391 ± 0.044	0.375 ± 0.070	0.322 ± 0.105	0.396 ± 0.070

such, spontaneous fracture history and flaccid lower extremity muscles were exclusion criteria. These factors may be related to BMD, and as such, the values given in this paper may be overestimating mean BMD in children with SCI.

The values for the BMD at the hip in this group of children were consistent with the previously published findings of hip BMD in children (13), with values that were approximately 60% of normal, or a Z-score that indicated a 1.6 to 1.8 SD reduction in BMD compared with age- and sex-matched peers. Lazo et al (17) determined that, in adults with SCI, each unit of SD decrement at the femoral neck compared with age-matched controls increased the risk of fracture in the lower extremity by 2.8. If the same trend holds, children in this study were 4.6 times more likely to sustain a lower extremity fracture, a rate that is higher than that reported for adults (9). However, the interpretation of the Z-scores do need to be approached with caution, because the BMD values reported for the children with SCI in this study were compared with a normative database collected by another center with different equipment. However, the degree of difference between the children in this study and the normative data was 40%, which is well beyond the potential error rate in using data from different machines (18).

The BMD for the children in this study was 0.38 ± 0.10 g/cm² for the distal femur and 0.37 ± 0.07 g/cm² for the proximal tibia. Because no normative data have been published for children without disability, it is not

possible to make comparisons at the knee between subjects in this study and subjects without disability or to determine whether subjects in this study had reached the two-thirds reduction in bone mass that places the knee at fracture threshold (19). However, the average BMD values were equivalent to those reported for adult-onset SCI at the knee (14), in which the values have been reported to be 30% to 40% lower than age- and sex-matched peers. The question is whether this BMD deficit will remain constant as the child grows or whether the gap will widen as several mechanisms for bone development are absent because of the SCI. From this study, trend for lower BMD values across all regions for children more than 2 years from their injury compared with those less than 2 years after injury suggests that BMD may decrease even in the presence of growth and skeletal maturation and is supported by the study by Kannisto et al (20) on BMD status in adults with pediatric-onset SCI. This, however, will need to be explored in a longitudinal study following children with pediatric-onset SCI as they mature.

The BMD data, stratified by sex and level of injury, seem to follow the same trends as in adults with SCI (1,13–15), although the sample size and large variation preclude a statistical comparison. The boys in this study had, on average, higher BMD values than the girls, and individuals with a thoracic injury had higher BMD values than the individuals with a cervical injury. Also, there was a trend toward a lower relative BMD distally to proximally; however, individual cases did not seem to follow this

Table 3. BMD Values Averaged Across Regions for All the Subjects in the Study and Categorized According to Time Since Injury

	<2 years (n = 9)	>2 years (n = 19)
Total hip	0.547 ± 0.105	0.447 ± 0.183
Femoral neck	0.580 ± 0.108	0.434 ± 0.177
Greater trochanter	0.410 ± 0.129	0.413 ± 0.183
Ward's triangle	0.499 ± 0.162	0.456 ± 0.175
Distal femur	0.436 ± 0.100	0.359 ± 0.091
Proximal tibia	0.395 ± 0.072	0.356 ± 0.073

pattern. The reasons for this are unknown but may be correlated to the age at the time of injury or perhaps how long the child was weight bearing and ambulatory before the injury. The children in this study sustained a SCI at a relatively young age, and therefore, the possibility of abnormal bone growth and development could have a confounding effect on the data and be one of the reasons for the individual deviations. This would need to be examined in a much larger sample size, with monitoring throughout the skeletal development of the child.

CONCLUSION

This is the second study to report on BMD in children with SCI and the first to provide information about BMD values at the knee. Children with SCI seem to have a substantially lower BMD at the hip in comparison with children without disability, placing them in the same risk category for lower extremity fractures as adults with SCI. A similar trend may also be present at the knee. Further study is warranted into BMD changes in individuals with pediatric-onset SCI as they mature into adults to determine whether there is an increased risk of fracture and what interventions can be done during childhood to reduce their current and future fracture risk.

ACKNOWLEDGMENTS

Funding for this study was provided by Shriners Hospitals for Children Grant 8540. The authors thank the Department of Radiology at Temple University Hospital and Oluwabunmi Oladeji, PT, for their assistance.

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