Muscle-Bone Characteristics in Children with Prader-Willi Syndrome

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Background: A decrease in muscle mass, low motor performance, and normal lumbar spine bone mineral density (BMD) have been reported in children with Prader-Willi syndrome (PWS). However, these data are limited by the fact that PWS children (who have short stature) were compared to age-matched healthy or obese individuals of normal height.

Objective: The goal of the present study was to compare bone and muscle characteristics in PWS children to sex- and age- or height-matched healthy subjects.

Materials and Methods: The study population included 17 PWS children (ages 6.2 to 17.5 yr; nine girls) who were not treated with GH. The axial skeleton was analyzed at the lumbar spine using dual-energy x-ray absorptiometry, and the appendicular skeleton (radius and tibia) was evaluated using peripheral quantitative computed tomography. Muscle parameters (mass, size, and functional parameters) were measured by dual-energy x-ray absorptiometry, peripheral quantitative computed tomography, and jumping mechanography, respectively.

Results: Compared to height-matched controls, PWS patients had normal axial and appendicular BMD, as well as normal muscle size. Compared to age- or height-matched controls of normal weight, PWS patients had lower maximal muscle force and power relative to body mass during jumping. PWS patients had similar absolute maximal muscle force but lower absolute maximal power compared to age- or height-matched controls. Relationships between bone mass and muscle size and force were similar in PWS patients and in healthy subjects.

Conclusion: Relative to their height, PWS patients not treated with GH had normal axial and appendicular BMD, muscle size, and muscle-bone relationships. **(*J Clin Endocrinol Metab* 97: E275–E281, 2012)**

Prader-Willi syndrome (PWS) is the most frequent cause of syndromic obesity and occurs in about 1 in 15,000 live births (1). The syndrome evolves in two phases. The first stage of PWS is characterized by severe neonatal hypotonia, feeding problems, failure to thrive, and global developmental delay. The second stage begins at 2–3 yr of age and includes decreasing hypotonia, hyperphagia that may lead to morbid obesity, short stature, hypogonadism, cognitive difficulties, and characteristic behavioral traits. PWS results from the lack of paternal expression of the q11-q13 region of chromosome 15 caused by deletion (more than 70%), uniparental disomy (25%), imprinting center defects, or balanced translocations (2).

Motor performance is a major source of concern in PWS patients. Newborns are severely hypotonic, and although muscle tone improves after several months of age,

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Abbreviations: aBMD, Areal BMD; BMC, bone mineral content; BMD, bone mineral density; BMI, body mass index; CSA, cross-sectional area; DXA, dual-energy x-ray absorptiometry; Fmax, maximal force; LS-aBMD, lumbar spine aBMD; M2LH, multiple two-legged hopping; Pmax, maximal peak power; pQCT, peripheral quantitative computed tomography; PWS, Prader-Willi syndrome; S2LJ, single two-legged jump; vBMD, volumetric BMD.

PWS infants continue to suffer from muscle weakness with delayed motor development (3, 4). Persistence of motor problems has been suggested in childhood and adulthood. Indeed, decreased physical activity (5) and low score on standardized motor performance tests (6) have been reported in PWS patients. The causes of these motor problems are unclear, but they could be related to abnormal body composition and neuromuscular functioning (7). Most previous studies on this topic used dual-energy x-ray absorptiometry (DXA) and reported that patients with PWS have a specific body composition with an increase in fat mass and a decrease in lean mass (5, 8–10). Qualitative studies from muscle biopsies, in patients with PWS compared with other hypotonic children, have suggested primary muscle pathology including muscle fiber immaturity and abnormal muscle fiber type distribution (11). However, muscle abnormalities could also be secondary, due to defects in trophic influences on the developing muscle from the central nervous system or to a secondary phenomenon of disuse (12). Total body and lumbar spine bone mineral density (BMD) has been reported as being normal in children with PWS (10, 13) but low in adults with this disorder (14, 15).

All these studies were limited by the fact that patients with PWS (who have short stature) were compared with age-matched healthy or obese individuals of normal height. Many parameters for bone and muscle mass are height-dependent, and therefore problems with the interpretation of results can arise when comparing groups that differ in height (16). Moreover, the effect of PWS on long bone development and on muscle-bone relationships has not been specifically addressed.

The goal of the present study was to compare bone and muscle characteristics in PWS children to sex- and age- or height-matched healthy subjects. The axial skeleton was analyzed at the lumbar spine using DXA, whereas the appendicular skeleton (radius and tibia) was evaluated using peripheral quantitative computed tomography (pQCT). Muscle parameters (mass, size, and functional parameters) were measured by DXA, pQCT, and jumping mechanography, respectively.

Patients and Methods

Patient population

The study population included patients with a genetically confirmed diagnosis of PWS who were older than 5 yr of age and were followed at Sainte-Justine University Hospital in Montreal. Children receiving GH treatment were excluded because GH affects bone and muscle characteristics (13).

A total of 17 children and adolescents (eight boys, nine girls) with a median age of 14.6 yr (range, 6.2 to 17.5 yr) were included. Eleven children (65%) had a deletion of chromosome 15q11-q13, one had an isochromosome 15p, three had a maternal uniparental disomy, and in two children the diagnosis of PWS was confirmed by an abnormal parent-specific methylation imprinting within the PWS critical region (maternal inheritance only) using methylation analysis, but the underlying genetic defect was not identified.

Twelve patients (71%) had had GH stimulation tests [oral clonidine, 0.15 mg/m^2; and iv arginine, 500 mg/kg (maximum dose, 30 g)], and the median (range) values of peak GH levels were 0.95 μg/liter (0.2–9.6) upon clonidine stimulation and 1.5 μg/liter (0.4–8.7) with arginine stimulation. Nine of these 12 patients had peak GH levels below 5.5 μg/liter on two GH stimulation tests. Among the 10 patients of pubertal age, two had had spontaneous puberty, and eight (four girls, four boys) were receiving sex steroid replacement therapy for hypogonadotropic hypogonadism.

The study protocol was approved by the Research Ethics Committees of the Sainte-Justine University Hospital in Montreal, Quebec, Canada.

Clinical evaluation

Height was measured using a Harpenden stadiometer (Holtain, Crymych, UK). Weight was determined using digital electronic scales for infants and mechanical scales for older children and adults (Healthometer, Bridgeview, IL). Body mass index (BMI) was calculated as the ratio of weight in kilograms divided by the square of height in meters. Height, weight, and BMI measurements were converted to age- and sex-specific z-scores on the basis of reference data published by the Centers for Disease Control and Prevention (17).

Biochemical measurements

Serum total calcium, phosphate, and alkaline phosphatase were measured using colorimetric methods (Monarch; Instrumentation Laboratories Inc., Lexington, MA). Serum 25-hydroxyvitamin D was measured with RIA (Osteo SP; Incstar Corp., Stillwater, MN). The serum IGF-I concentration was measured by using a commercially available assay (RIA; Nichols Institute Diagnostics, San Juan Capistrano, CA), and results were converted to age- and sex-specific z-scores on the basis of published reference data (18).

Dual-energy x-ray absorptiometry

Fat body mass and lean body mass of the total body and lumbar spine (L2–L4) areal BMD (aBMD) were measured in milligrams per square centimeter by DXA using a Lunar Prodigy device (GE Healthcare, Waukesha, WI). Fat body mass was expressed as a percentage of total body mass. In two patients who had had scoliosis surgery, lumbar spine densitometry could not be performed owing to the presence of metal rods at this level. An estimate of three-dimensional bone density, commonly called volumetric BMD (vBMD; mg/cm^3), was calculated as described by Kroger *et al.* (19) using the formula: vBMD = aBMD $\times$ [4/($\pi \times$ width)], width being the mean width of vertebral bodies L2 to L4.

LS-aBMD (lumbar spine aBMD) results were transformed to age-specific z-scores using data provided by the densitometer manufacturer. Lumbar spine vBMD, percentage of fat body mass, and absolute lean body mass results were transformed to age-specific z-scores using data published by van der Sluis *et al.* (20).

Peripheral quantitative computed tomography

pQCT was performed at the radius and the tibia using the Stratec XCT2000 equipment (Stratec Inc., Pforzheim, Germany) as previously described (21, 22). In four patients, pQCT analyses were not performed for technical reasons.

Two measurements were performed at radial sites corresponding to 4% of forearm length (4% radial site) and to 65% of forearm length (65% radial site), representing metaphyseal and diaphyseal bone, respectively. Results of radial pQCT analyses were compared with the findings in a reference population of healthy children and adolescents, which have been previously described (21, 22).

Four measurements were performed at tibial sites corresponding to 4% (4% tibial site, corresponding to metaphysis), 14% (14% tibial site), 38% (38% tibial site), and 66% (66% tibial site) of the tibia length. Bone mineral content (BMC) was assessed at 4, 14, and 38% tibial sites, and muscle cross-sectional area (CSA) was assessed at the 66% tibial site.

Image acquisition, processing, and the calculation of numerical values were performed using the manufacturer's software package (version XCT 6.02, Stratec Inc.).

Compared with DXA, which can only measure an aBMD, pQCT provides an accurate assessment of vBMD at the long bone site. Moreover, pQCT analyses allow the determination of muscle-bone relationships.

Jumping mechanography

All measurements were recorded with the Leonardo Mechanograph Ground Reaction Force Platform (Novotec Medical GmbH, Pforzheim, Germany). The signal from the force sensors was analyzed using the Leonardo Mechanography GRFP Research Edition software version 4.2-b05.53-RES. Participants performed two different tests as previously described (23).

Multiple two-legged hopping (M2LH)

This test represents two-legged hopping on the forefoot with the aim to achieve a maximal ground reaction force. It evaluates the maximal force (Fmax) to which the tibia is exposed, and thus can serve to evaluate the muscle-bone unit (24). Fmax and Fmax relative to body mass (Fmax/body mass) were analyzed for this hop.

Single two-legged jump (S2LJ)

This is a vertical counter-movement jump to achieve maximum jump height. Parameters used for analysis were: jump height, maximal speed, Fmax (both legs combined, as well as left and right leg analyzed separately), Fmax/body mass, maximal peak power (Pmax; both legs together and left and right leg independently), and Pmax/body mass.

Statistical analyses

Raw results were transformed to sex- and age-, or height-specific z-scores or differences from the average result in the reference population using the reference data cited in the description of measurement techniques. The expected mean result of these transformed values in a healthy population is zero. The significance of the difference from zero was calculated by the one-sample *t* test. For results of tibial pQCT and jumping mechanography analyses, each patient with PWS was matched with a sex- and age-, or height-matched healthy subject selected in a reference population of 118 nonobese children and adolescents. Differences between patients with PWS and sex- and age-, or height-matched healthy subjects were tested for significance using the Wilcoxon test.

Associations are given as Spearman rank correlation. All tests were two-tailed, and throughout the study $P < 0.05$ was considered significant. These calculations were performed using the SPSS software, version 11.5 for Windows (SPSS Inc., Chicago, IL).

Results

Clinical, biochemical, and radiological characteristics were similar between girls and boys (Supplemental Table 1), and between patients with and without deletion of chromosome 15q11-q13, and therefore results of patients were analyzed as a single group.

Clinical and biochemical data (Table 1)

Compared with age- and sex-specific reference ranges, PWS patients on average were shorter and had a higher BMI (Table 1). Six PWS patients (35%) had short stature defined as a height z-score below −2, and 10 patients (59%) had obesity defined as a BMI z-score above 2.

Mineral homeostasis parameters (*i.e.* serum total calcium, phosphate, and alkaline phosphatase) were in the normal range for all patients. The median serum 25-hydroxyvitamin D concentration, evaluated in 15 children, was 74 nmol/liter (range, 41 to 108 nmol/liter), with concentrations below 50 nmol/liter in two patients (12%) and below 75 nmol/liter in eight patients (47%). Clinical, biochemical, and radiological characteristics were similar between children with sufficient vitamin D levels (≥50 nmol/liter) and children with insufficient levels (<50 nmol/liter).

The median serum IGF-I level, evaluated in 17 children, was 19.5 nmol/liter (range, 9.0 to 28.7 nmol/liter) with an IGF-I z-score below −2 in 13 of 17 children (76%). Serum IGF-I levels were correlated with age ($r = 0.52$; $P = 0.04$) but were not correlated with parameters reflecting bone

TABLE 1. Clinical, biochemical, and radiological results of patients with PWS

Variable	n	Median (minimum; maximum)	*P*
Gender (males/females)	17	8/9	
Age (yr)	17	14.6 (6.2; 17.5)	
Height (z-score)	17	−1.6 (−3.2; −0.3)	<0.0001
Weight (z-score)	17	1.5 (−1.3; 3.7)	0.003
BMI (z-score)	17	2.1 (0.1; 3.0)	<0.0001
LS-aBMD (z-score)	15	0.2 (−2.6; 2.8)	0.82
LS-vBMD (z-score)	15	0.4 (−1.9; 3.9)	0.15
Fat body mass % (z-score)	17	2.5 (1.8; 3.3)	<0.0001
Lean body mass (z-score)	17	−2.4 (−5.1; 1.4)	0.001

P values for comparison to normal reference data by one sample *t* test. LS-vBMD, vBMD of the lumbar spine.

TABLE 2. pQCT results at the radial metaphysis (4% site) and the radial diaphysis (65% site) in 13 patients with PWS

	Age- and sex-dependent z-score	Height- and sex-dependent z-score
Metaphysis		
BMC	−2.0 (−3.5; 0.7)**	0.2 (−0.9; 1.6)
Total CSA	−2.2 (−4.3; 0.6)**	0.1 (−2.1; 1.6)
Total vBMD	0.3 (−1.8; 1.9)	0.8 (−1.1; 3.7)
Trabecular vBMD	−0.4 (−2.9; 2.3)	−0.1 (−2.4; 2.1)
Cortical thickness	−0.1 (−5.6; 1.6)	1.0 (−8.3; 3.2)
Diaphysis		
BMC	−0.8 (−2.7; 1.2)*	0.9 (−0.5; 1.8)*
Total CSA	−1.6 (−3.2; 0.3)**	−0.4 (−2.0; 0.7)
Total vBMD	0.1 (−0.7; 2.4)	0.9 (−0.4; 2.6)**
Cortical CSA	−1.4 (−2.9; 1.2)*	0.7 (−1.2; 2.2)
Cortical/total CSA	0.2 (−0.6; 2.1)	0.6 (−0.5; 2.6)**
Cortical vBMD	0.4 (−0.8; 2.5)	1.7 (−0.4; 2.4)**
Strength-strain index	−2.0 (−3.5; 0.1)**	0.1 (−2.2; 1.1)
Muscle CSA	−1.0 (−4.8; 0.9)**	0.8 (−1.5; 1.3)
BMC/muscle CSA	0.4 (−1.3; 2.9)	

Values are expressed as median (minimum; maximum). The significance of the difference to zero calculated by one-sample *t* test is shown by *asterisks*: *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

mass (vBMD at the lumbar spine and at the radial metaphysis and diaphysis; BMC at the radial metaphysis and diaphysis and at the 4, 14, and 38% tibial sites), muscle mass (lean body mass, forearm and calf muscle CSA), or muscle force (Fmax during M2LH).

DXA measurements (Table 1)

Compared with age- and gender-specific reference data, fat body mass was increased, and lean body mass was decreased (Table 1). Median fat mass expressed as a percentage of total body mass was 51%, ranging from 26 to 63%. Lumbar spine aBMD and vBMD values were within the respective reference ranges (Table 1).

Forearm pQCT analyses (Table 2)

Total, trabecular, and cortical vBMD were similar to age- and sex-specific mean values in healthy subjects. Compared with height- and sex-specific reference values, total and cortical vBMD at the diaphysis of patients with PWS were elevated.

Metaphyseal and diaphyseal BMC values were 26 and 11%, respectively, below the result expected for age-matched healthy subjects. This was due to small bone (*i.e.* total CSA was low). Compared with height-matched reference values, BMC was normal. Similarly, forearm muscle size (*i.e.* muscle CSA) was 13% lower than in the age-matched reference population, but it was similar to that of healthy subjects matched for height. The relationship between muscle and bone (*i.e.* the ratio between diaphyseal BMC and muscle CSA) was normal, and when compared with a reference population with the same height, patients with PWS had the same strength-strain index that is used as a parameter of bone strength.

Tibia pQCT analyses (Table 3)

Similarly to the findings at the radius, BMC values at the 4, 14, and 38% tibial sites were similar compared with a height-matched reference population. Despite similar muscle size, muscle density in patients with PWS was lower than in height-matched healthy subjects.

Muscle CSA was positively correlated with BMC at the 14% tibial site, and the linear regression equations for PWS and for controls were similar (Fig. 1A).

TABLE 3. Jumping mechanography and pQCT results at the 4, 14, and 38% tibial sites in patients with PWS

	n	PWS patients	Age- and sex-matched controls	*P*	Height- and sex-matched controls	*P*
Age (yr)	15	14.7 (6.2; 18.0)	14.6 (6.2; 17.4)	0.26	11.0 (6.1; 15.6)	0.003
Weight (kg)	15	58.0 (23.2; 128.2)	53.1 (18.3; 85.0)	0.09	41.6 (18.3; 72.3)	0.003
Height (m)	15	1.47 (1.10; 1.58)	1.64 (1.09; 1.80)	0.002	1.48 (1.09; 1.60)	0.49
pQCT at the tibia						
BMC 4% (mg/mm)	13	211 (97; 259)	267 (98; 363)	0.013	186 (98; 307)	0.93
BMC 14% (mg/mm)	13	182 (108; 238)	213 (89; 278)	0.11	155 (89; 222)	0.48
BMC 38% (mg/mm)	13	331 (194; 444)	345 (150; 482)	0.09	266 (150; 392)	0.37
Muscle CSA 66% (mm^2)	13	4227 (2924; 5709)	5353 (2445; 7276)	0.03	4538 (2445; 7060)	0.72
Muscle density (mg/cm^3)	13	69.6 (59.8; 72.2)	72.9 (65.0; 82.8)	0.03	71.6 (68.4; 82.8)	0.008
M2LH						
Fmax (kN)	15	1.80 (0.83; 3.68)	2.34 (0.63; 3.71)	0.17	1.59 (0.63; 2.22)	0.06
Fmax/body mass (kN/kg)	15	3.18 (2.10; 5.09)	4.67 (2.97; 5.75)	0.005	3.93 (3.12; 5.65)	0.01
S2LJ						
Jump height (m)	15	0.15 (0.08; 0.36)	0.39 (0.16; 0.59)	0.001	0.37 (0.16; 0.40)	0.001
V_{max} (m/sec)	15	1.34 (0.94; 2.23)	2.41 (1.65; 3.05)	0.001	2.24 (1.65; 2.43)	0.001
Pmax (kW)	15	1.25 (0.46; 2.02)	2.37 (0.50; 4.13)	0.001	1.61 (0.50; 2.80)	0.16
Pmax/body mass (W/kg)	15	19.5 (14.2; 35.3)	44.7 (27.5; 66.8)	0.001	38.0 (27.5; 44.8)	0.001
Fmax (kN)	15	2.16 (1.72; 3.23)	2.17 (1.76; 2.86)	0.69	2.23 (1.76; 2.76)	0.53
Difference Fmax left/right (%)	15	5.8 (1.7; 16.1)	5.0 (0.1; 14.4)	0.95	5.1 (0.3; 22.8)	0.82

Values are expressed as median (minimum; maximum). *P* values were calculated using the Wilcoxon test. V_{max}, Maximal speed.

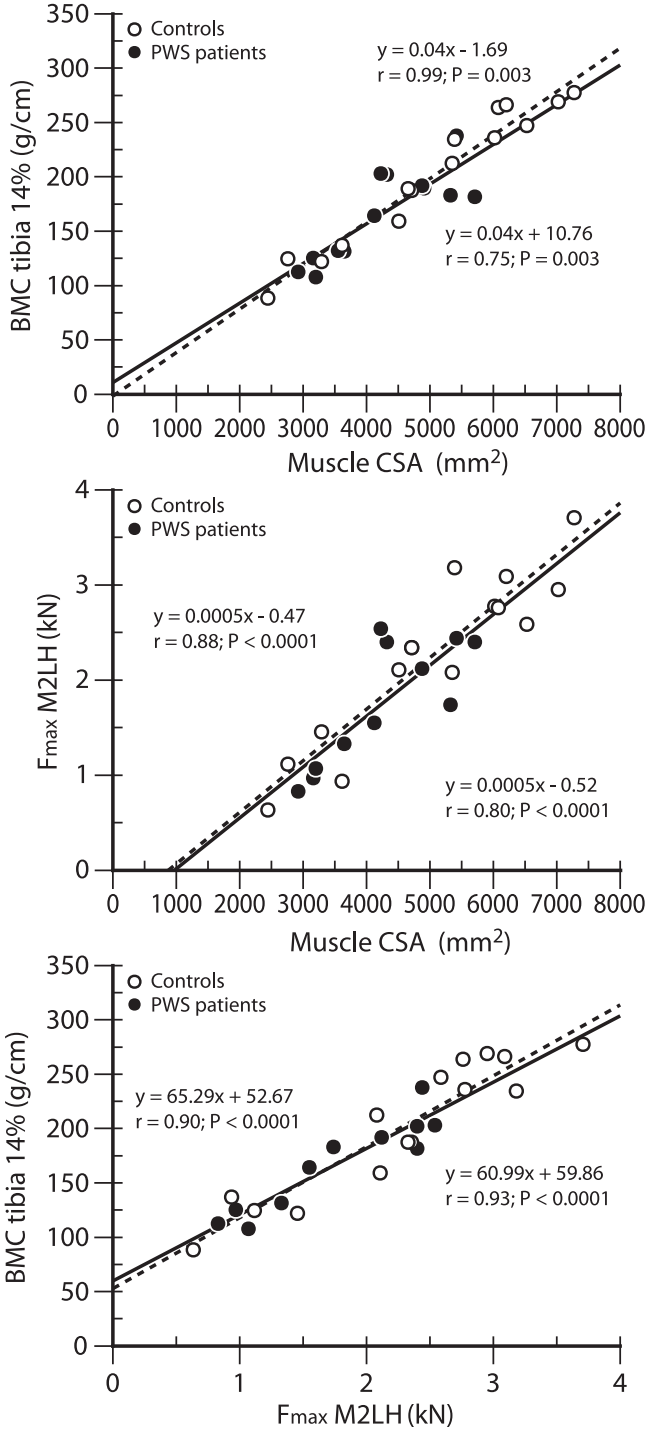

FIG. 1. Relationships between BMC at 14% tibial site (BMC14%) and muscle CSA at 66% tibial site (muscle CSA) (A); muscle CSA and M2LH (Fmax M2LH) (B); and Fmax M2LH and BMC14% in patients with PWS and age-matched healthy subjects (C).

Jumping mechanography (Table 3)

Compared with age- or height-matched controls of normal weight, PWS patients had lower maximal muscle force and power relative to body mass during jumping. When the parameters were expressed as absolute value, PWS patients had maximal muscle force during M2LH similar to age- or height-matched controls. However, PWS patients had lower absolute maximal power during S2LJ compared with healthy controls, but significance was reached only when compared with age-matched controls.

Maximal force during M2LH was positively correlated with muscle size at the 66% tibial site, and the linear regression equations for PWS and for age-matched controls were similar (Fig. 1B). In healthy subjects, it has been demonstrated that maximal muscle force during jumping is strongly associated with tibial BMC most specifically at the 14% tibial site (25). This is explained by the fact that minimal bending measures occur at this location where tibia mainly consists of cortical bone (26). In patients with PWS, the same positive association was found between maximal force during M2LH and BMC at 14% tibial site, and the linear regression equations for PWS and for controls were similar (Fig. 1C).

Discussion

This study is the first to examine the bone and muscle relationship in PWS and to take into account the importance of stature in the interpretation of the parameters studied. GH treatment is not approved in Canada for patients with PWS and is often withheld by treating physicians and/or parents, even in GH-deficient obese PWS patients, because of the fear of complications. Thus, we had access to a unique and contemporary cohort of patients who were not receiving this anabolic treatment.

We found that, compared with age-matched healthy controls, children with PWS were shorter and heavier but had similar aBMD at the lumbar spine, confirming earlier studies in children with PWS (13). At the appendicular skeleton, which has not been studied to date in this population, pQCT analyses revealed that PWS patients had lower BMC at several measurement sites. However, bone size-independent pQCT measures (trabecular vBMD, total vBMD, and cortical BMD) were similar between the PWS group and age-matched controls, suggesting that bone mass differences between these groups mostly reflected differences in bone size. Indeed, when compared with height-matched controls, patients with PWS had normal or even elevated BMC. Thus, we did not detect an obvious skeletal abnormality in this group of patients with PWS. It must be noted, however, that in addition to premature pubarche reported in PWS patients (27), our eight patients with hypogonadotropic hypogonadism received hormone replacement therapy from the normal age of puberty onset, and therefore none of them was deficient in sex steroids.

Not surprisingly, the PWS group had a very low lean body mass (a surrogate measure of muscle mass), compared with age-matched healthy controls, confirming earlier studies on

the body composition of PWS patients compared with age- or weight-matched healthy subjects (5, 8–10). Compared with age-matched controls, PWS patients also had low muscle CSA at the forearm and at the lower leg. It has to be considered, however, that muscle size correlates with height (28). Indeed, when compared with height-matched controls, PWS patients had normal muscle CSA. Lower muscle density observed in our patients may be related to increased muscle lipid content (29).

As for muscle function, as expected, compared with age- or height-matched controls of normal weight, PWS patients (who were heavier) had lower maximal muscle force and power relative to body mass during jumping. Weight-dependent measures (jump height and maximal speed during S2LJ) were also lower in PWS patients than in healthy subjects. However, when absolute values were considered, maximal muscle force during M2LH in patients with PWS was similar to age- or height-matched controls. The trend of having higher absolute maximal force values in patients with PWS compared with height-matched controls is probably due to the difference in age, and consequently in pubertal development, between these two groups. The similar relationship between maximal force during M2LH and muscle size for PWS and for age-matched controls also suggests normal absolute muscle force in PWS patients. In contrast, absolute maximal muscle power during S2LJ in patients with PWS was significantly lower than in age-matched controls and tended to be lower than in height-matched controls. Muscle power is influenced by a variety of factors, such as muscle force, body mass, coordination, balance, and jumping technique. Thus, it has been described that obese subjects compared with healthy subjects have impaired muscle power during jumping despite an increased absolute isotonic muscle force (30). PWS patients also have abnormal gait pattern and balance capacity compared with both matched obese and healthy subjects, which could also modify muscle performance (31–33).

The mechanostat theory postulates that bone adapts to the mechanical forces to which it is subjected to keep the strain on the bone at a constant set point (functional muscle-bone unit) (34). Thus, an increase in muscle mass corresponds with an increase in bone strength (35). In patients with PWS, BMC at 14% tibial site was positively correlated with muscle size and maximal force during M2LH, and the regression equations were similar to those in healthy controls, suggesting a normal functional muscle-bone unit.

Although our study is original, it has several limitations. The sample size was limited; however, it was similar to that of previous studies regarding neuromuscular functioning in PWS (7). Choice of an appropriate control group is also problematic. In previous studies, patients with PWS (who have short stature) were compared with age-matched healthy or obese individuals of normal height. Young PWS patients are short and obese, compared with healthy children, and the difference in height is even larger when they are compared with obese children because obese children tend to be tall (36). Consequently, it is difficult to find a control group that is matched for both height and weight. Because many parameters for bone and muscle mass are height-dependent (16), we decided to compare patients with PWS to height-matched healthy subjects. However, this control group did not allow us to discuss certain characteristics such as maximal muscle force and power relative to body mass during jumping, which are usually considered the main outcome parameters for this test. Finally, the fact that absolute maximal muscle force was normal in PWS patients suggests that mental retardation did not interfere with their jumping performance.

Conclusion

Relative to their height, PWS patients not treated with GH had normal axial and appendicular BMD, muscle size, and muscle-bone relationships. Despite low muscle power, PWS patients had similar absolute maximal ground reaction force during jumping compared with healthy subjects. The objective characterization of muscle function performed in this study provides valuable baseline data for further research on the effectiveness of exercise and/or GH treatment on muscle function in PWS patients, both of which have been shown to improve muscle strength and motor performance in these patients (37, 38).

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