Midfemoral Bone Volume of Walking Subjects with Chronic Hemiparesis Post Stroke

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Background and Purpose: Muscle and bone form a functional unit. Residual physical poststroke impairments such as muscle weakness, spasticity, and decrease in function can promote metabolic bone changes. Moreover, muscle strength can influence this process. Thus, the purpose of the present study was to investigate bone volume and mobility performance in subjects with chronic hemiparesis post stroke. *Methods:* A cross-sectional study was performed on 14 subjects post stroke who were paired with healthy controls. Bone volume, isometric muscle performance, and mobility levels were measured. Midfemoral bone volumes were determined using magnetic resonance imaging, and muscular performance was measured by dynamometry. Mobility was measured using the Timed Up and Go Test and the 10-Meter Walk Test. *Results:* Regarding bone volume total, there was no difference in the medullary and cortical groups ($P \geq .05$). During torque peak isometric flexion, the paretic group was significantly different compared with the other groups ($P = .001$). However, the control presented no difference compared with the nonparetic limb ($P = .40$). With regard to the extension isometric torque peak, the paretic limb was significantly different compared with the nonparetic ($P = .033$) and the control ($P = .001$) limbs, and the control was different from the nonparetic limb ($P = .045$). Bone volume variables correlated with the isometric torque peak. *Conclusions:* Chronic hemiparetic subjects maintain bone geometry compared with healthy volunteers matched by age, body mass index, and gender. The correlation between bone volume midfemoral structures and knee isometric torque was possible. **Key Words:** Neurological rehabilitation—physical therapy—stroke—bone volume—functionality.

Introduction

Loss of muscle mass and low bone mineral density are considered as indicators of functional decline.[1] This decrease is present in the natural aging process because of the combination of various etiologic factors, such as the biomechanical stimuli depletion and metabolic changes, which may culminate in osteoporosis, falls, and consequently, fractures.[2,3] Majority of stroke survivors have reduced paretic limb function, which may worsen bone loss.[4,5]

There is evidence that bone geometric architecture (the size, the shape, and the bone mass distribution) is an important determinant of bone strength.[6] Bone resistance is intimately related to the cortical bone geometry,[7] and

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bone remodeling is related to the medullary structure. These bone portions exhibit anisotropic characteristics; that is, the capacity of bone has different mechanical properties when stressed in different directions because of its directional structure.[8] In this sense, the characterization and the monitoring of geometric architecture are important measures that can improve the prevention of diseases related to bone metabolism.

Dual-energy x-ray absorptiometry and bone density index are the main resources to measure bone geometry. The volumetric bone geometry measured on magnetic resonance imaging (MRI) is a possibility that enables assessment of muscular and bone structures. Studies have shown that MRI presets accuracy and repeatability compared with these gold pattern resources to measure bone mass.[9-12] These authors described and validated the midfemoral bone geometry, which has acceptable accuracy and repeatability in both subjects who are healthy and subjects with osteoporosis. Also, midfemoral bone geometry methodology, which includes both cortical and medullary bone structures, has been applied to athletes,[11] children,[10] and adults.[12]

Therefore, the present study aimed to determine whether chronic hemiparetic subjects present with changes in bone geometry and to verify the correlation between knee isometric torque, mobility capacity, and midfemoral bone volume variables. The hypothesis generated in this work is that there should be a direct correlation between bone volume and mobility capacity in hemiparetic subjects who present considerable chronicity levels. The approach applied in this work is interesting because it encourages the practice of muscle and bone investigation in the same examination. The possibility of investigating both aspects is important to facilitate the prevention process in subjects who present symptoms of a decline in strength.[13] If a decline in geometry was identified, the specific examination regarding the osteoporosis protocol can be prescribed. In addition, observing the chronic stroke impacts on strength, function, and bone geometry is important to act more efficiently to prevent falls, fractures, and comorbidities associated with bone maintenance. Moreover, it allows clarification of the musculoskeletal changes after a stroke.

Materials and Methods

Design Study and Subjects

This was a cross-sectional study. Twenty-eight subjects took part in the study. The hemiparetic group (N = 14) consisted of 12 men and 2 women with ischemic (n = 9) or hemorrhagic (n = 5) unilateral stroke. The mean time after stroke was 7.31 years (standard deviation = 6). The control group (N = 14) also consisted of 12 men and 2 women who were matched to the hemiparetic group by age (±3 years), gender, and body mass index (±4 kg/m^2). The initial control population was recruited from a waiting list of subjects in a physical activity program, and the hemiparetic subjects were enrolled from a local medical center's waiting list. The hemiparetic subjects were not linked to any rehabilitation programs. The study was conducted according to the guidelines and standards for human research (Resolution 196/1996, the National Health Council) and was approved by the local ethics committee (report number 278/2011). The statistical power was calculated at the end of the study using the medullary bone volume variable (power = .94, effect size = .56).

Inclusion and Exclusion Criteria

The following inclusion criteria were considered: 6 or more months post stroke, men or women aged between 50 and 70 years, low spasticity (less than level 3 on the Modified Ashworth Scale[14] so that the subject would be able to perform the isokinetic test), and walking ability classified to 2-5 levels according to the Functional Ambulation Categories (FAC) test.[15] Regarding an important aspect, sedentarism, which can promote deleterious modifications in the neuromuscular system, control subjects had to score greater than 8 on the Physical Activity Questionnaire Basal, which indicates they are not sedentary.[15] Furthermore, subjects from the control group performed physical activity (mainly aerobic activities) at least 3 times weekly. No further criteria regarding physical activity level was applied. The exclusion criteria were as follows: clinical signs of severe heart failure or chronic metabolic disease, other orthopedic or neurological diseases that would impair data collection with MRI or isokinetic strength testing, pacemakers or heart valves, metal implants, severe cognitive or communication impairments, minimum score on the Mini-Mental State Examination[16] according to education level, and history of knee damage or lower limb injuries.

Procedures and Measuring Instruments

Mobility Assessment of the Hemiparetic and Control Groups

For a detailed description of the hemiparetic group, the motor performance was assessed with the Fugl–Meyer Assessment,[17] the mobility was assessed with the adapted "Timed Up and Go" Test[18] and the 10-Meter Walk Test.[19]

Isokinetic Assessment

The maximal isometric contractions were obtained during isokinetic knee extension and flexion movements on a Biodex System III dynamometer (Biodex Medical Systems, Shirley, NY). The participants were positioned following the manufacturer's recommendations. For the strength measurements, we considered 0° as full knee extension, and the testing range of motion was set to 20°. Both limbs were evaluated. The nonparetic limb was tested first, and the choice of the first limb for the control group was performed by randomization. The maximal isometric contractions were performed twice (familiarization and test).[20] The data from the Biodex System were processed with MATLAB software (v.7.0.1; MathWorks, Natick, MA).

Magnetic Resonance Imaging (MRI) and Bone Volume

Volunteers were scanned in a .35-T Magnetom C! System (Siemens Healthcare, Erlangen, Germany) using a standard body coil. Axial images were acquired perpendicular to the long axis of the femur using a conventional 2-dimensional spin echo sequence with the following parameters: repetition time and echo time = 790 and 16 ms, field of view = 400×400 mm^2, matrix = 256×256, slice thickness = 9 mm, and 2 averages.[21] Images were exported in DICOM (National Electrical Manufacturers Association, Arlington, USA) and converted to Analyze 7.5 (Mayo Clinic, Minnesota, USA) employing routines locally implemented using MATLAB. Regions of interest were manually drawn to assess the cross-sectional area of cortical and medullary midfemoral regions using MRIcro (www.mccauslandcenter.sc.edu/crnl/tools). The total volume of each area of interest was determined by the multiplication of the cross-sectional area, the slice thickness, and the number of slices. The result was expressed in cubic centimeter. The midfemoral volume was normalized by body weight values.

Statistics

The data were tested for normality and homogeneity (Shapiro–Wilk and Levene tests, respectively). A 2-way analysis of variance performed to identify possible interactions among factors are the following: the lower limbs (dominant and nondominant) and condition (paretic, nonparetic, and control) and differences among groups (paretic, nonparetic, and control). The data from both limbs of the control group were pooled for the control data because the lower limb dominance did not show any difference. Tukey post hoc tests were applied to the comparisons in which significant differences were observed. The dependent variable was knee isometric peak torque during extension and flexion. An unpaired Student t test was used to assess differences between groups for the Timed Up and Go Test and the 10-Meter Walk Test, and demographic variables. Kruskal-Wallis and Mann-Whitney U tests followed by Bonferroni adjustment ($P = .0017$) were used to assess differences between groups for midfemoral bone volume. A Spearman correlation was used to examine the relationship between isometric torque and mobility. A .05 alpha level with a 95% confidence interval was used for all statistical tests, which were performed using SPSS software (version 10.0; SPSS Inc., Chicago, IL).

Table 1. *Sample functional and demographic description*

Variables	Control (n = 14)	Hemiparetic (n = 14)	*P* value
Age (y)	61.6 ± 8	61 ± 8	.818
Height (m)	1.66 ± .05	1.65 ± .08	.835
Body weight (kg)	73.1 ± 13.9	70.34 ± 8.84	.963
Body mass index	26.31 ± 3.95	25.86 ± 3.23	.679
TUG Test (s)	8.17 ± 1.66	26.16 ± 17.93*	.001
10-Meter Walk Test (m/s)	1.89 ± .32	.80 ± .53*	.001

Abbreviation: TUG, Timed Up and Go.
*Significant difference between groups.

Results

Subjects Characteristics

Recovery Lower Limbs Function

The Fugl–Meyer mean score was 28.4 ± 1.86 (84%), which indicates a marked motor impairment. The Functional Ambulation Category values were level 4 (n = 7) and level 5 (n = 7). The Modified Ashworth Scale values were as follows: hip: 0 (n = 11), 1 (n = 1), 1+ (n = 2); knee: 0 (n = 6), 1 (n = 5), 1+ (n = 2), 2 (n = 1); and ankle: 0 (n = 3), 1 (n = 8), 1+ (n = 1), 2 (n = 2) (For more informations, please, see Table 1).

Isometric Contractions

Significant differences were identified between groups during both movements (p>0.05). Please see Figure 1.

Bone Volume

There was no significant difference between the groups (Figure 2).

Correlations

Total ($R = .7$, $P = .01$) and medullary ($R = .65$, $P = .03$) bone volumes of the nonparetic group correlated with isometric peak torque flexion. There were no significant changes for the other variables related to function, torque, and bone volume ($P \geq .05$) (Figure 3).

Discussion

Chronic hemiparetic subjects require maintenance of bone geometry compared with healthy volunteers matched by age, body mass index, and the gender. It is known that the relation between force levels and maintaining bone mass in other populations is not possible in the present study, considering that the weakness and mobility levels of the paretic limb were not correlated with midfemoral maintenance.[13] However, unprecedented information was observed. The nonparetic knee flexion was correlated with

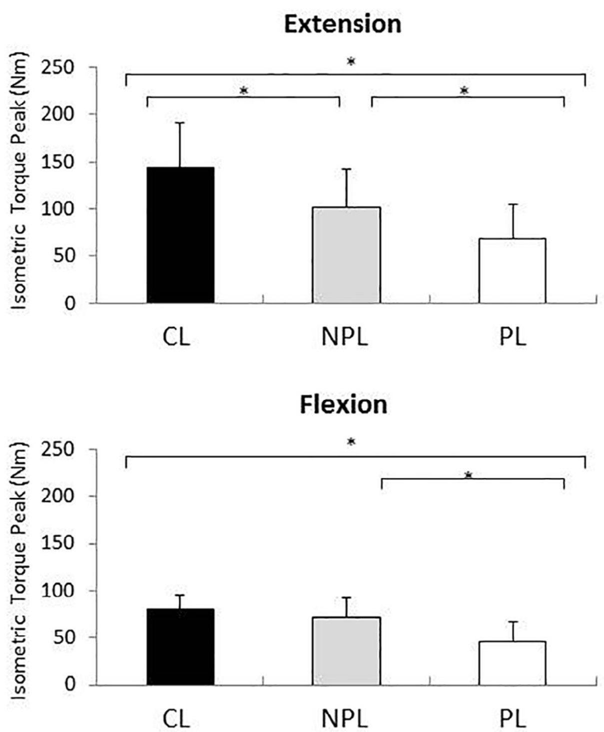

Figure 1. *Maximum isometric peak torque. The PL group was significantly different when compared with the NPL (P = .033) and the CL (P = .001) groups during the isometric peak torque extension, and the CL group was different from the NPL group (P = .045). The PL group presented a difference compared with the NPL (P = .001) and the CL (P = .001) groups. The CL group did not present a difference compared with the NPL group (P = .4) during the isometric peak torque flexion. Abbreviations: CL, control; NPL, nonparetic; PL, paretic.*

total and medullary bone volumes, and both represent the maintenance and recuperation levels. In addition, the nonparetic force and the midfemoral bone are similar to the control group.

Regarding the upper limbs, muscle weakness is a major determinant of bone mass and geometry in the midshaft radius of chronic stroke survivors.[22] Yang and Pang (2015)[23] assessed concentric knee muscle function, which was associated with the bone strength index in the diaphyseal tibial region and identified a significant side-to-side difference in total volumetric bone mineral density (vBMD), trabecular vBMD, cortical vBMD, cortical area, cortical thickness, and bone strength index in the hemiparetic group. However, the present study demonstrated that subjects with chronic hemiparetic had no reduction in the midfemoral bone volume, even though they had lower levels of strength compared with the control and the nonparetic groups.

Furthermore, when the paretic knee extensors demonstrated exaggerated weakness at short muscle lengths, the nonparetic knee extensors and flexors demonstrated selective strength gains. Lomaglio and Eng[24] showed that nonparetic limbs performing the majority of the effort during sit-to-transfer are being loaded to near maximal levels repeatedly throughout the day. Interestingly, the activities of the quadriceps and the hamstrings in older adults peak during the critical transition phase of sit-to-stand when the knee is flexed beyond 90°. Thus, such repetitive activity of the nonparetic knee could result in compensatory strength gains over a flexed joint position.

Regarding the activity levels, the balance and endurance were associated with the tibial bone strength in the paretic limb in a previous study. In addition, the close relationship between muscle strength and bone health is evident in the upper extremity.[22] Individuals with stroke sustained an elevated risk of fragility fractures because of 2 reasons: reduced ability to regain the independent mobility function and mineral bone loss. However, the midfemoral bone volume of chronic hemiparetic subjects did not present correlations to mobility tests. Thus, moderate levels of mobility promote sufficient stimulus to maintain the midfemoral bone volume, similar to the healthy age-matched group. In addition, age would be a critical factor, considering that hemiplegic patients present fractures after the age of 70, which is 10 years older than the study population.[3] Strength and bone volume were correlated. Therefore, studies that included higher levels of impairment and several different ages should be proposed.

It is known that in subjects post stroke, both limbs are altered by central nervous system injuries. In addition, the nonparetic limb adapts to an increased demand. The present study verified that the bone volume is correlated with the flexor torque of the nonparetic limb of these subjects. According to the authors,[25] the nonparetic limb has a change in coordination related to compensations observed during gait. The nonparetic limb is related to the flexor activity of the knee where the early stance plantar flexion activity provided propulsion because of the decreased advancement of the nonparetic foot. It is also known that compensation strategies generate patterns of undesirable asymmetrical movements. However, considering patients with severe hemiplegia, the nonparetic adaptations are important; for example, the isometric knee flexion in the nonparetic limb may be useful for facilitating the paretic rectus femoris and tibialis anterior muscular activities.[25]

Clinical Appointments- Since these patients have moderate levels of functional recovery without any observed bone loss by geometric analysis, there is the question of how this relationship would be for patients with hemiparesis who are older and have several impairments. An important point to consider is a study of prospective information, for example, post immobilized time, because there is evidence that immobility in the first months after stroke is a key risk factor for osteoporosis and fractures.[5,26] Because the influence of stroke impairments on bone was region specific, it is necessary to quantify the femoral neck bone volume to understand the real predisposition to fractures in this population, whereas the femoral neck is the critical region of fractures in the older population. Therefore,

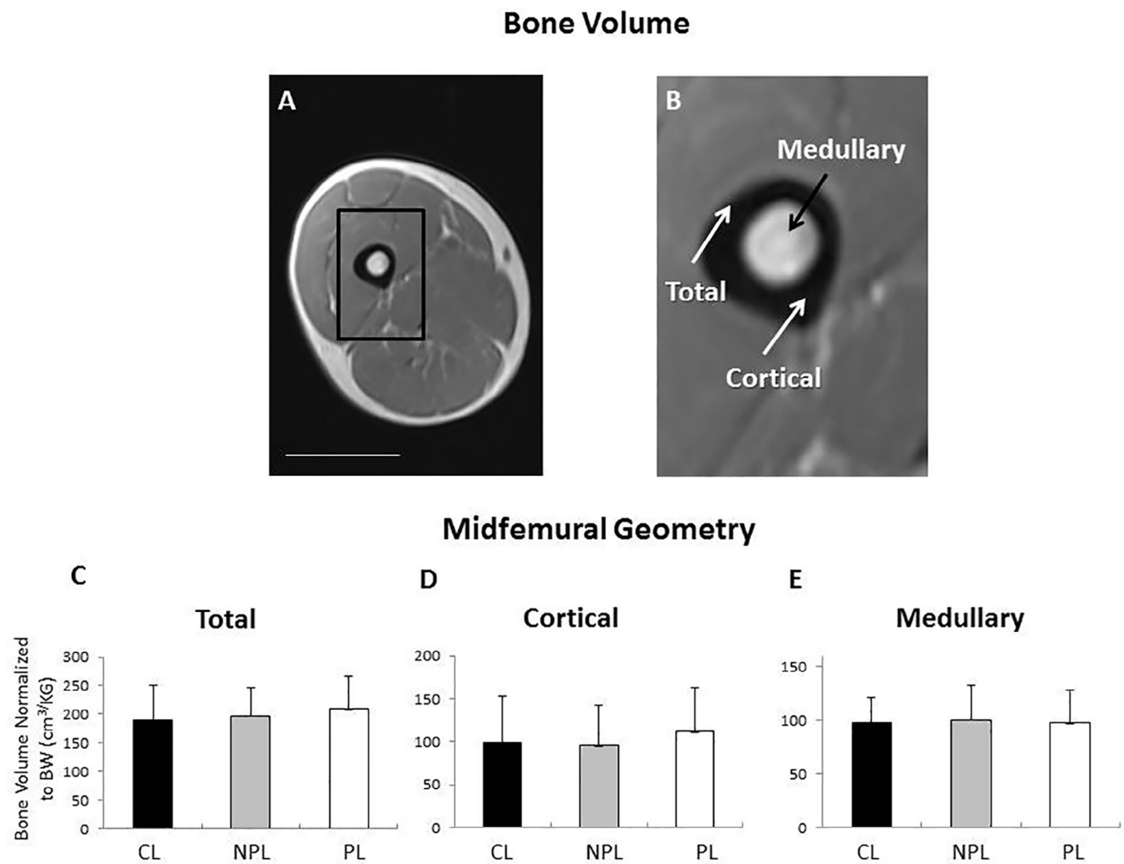

Figure 2. *Bone volume and midfemoral geometry. The first part of the figure (A and B) represents the cross-sectional area acquired by magnetic resonance imaging. The bar represents 1.5 cm. Part B is a section of part A and is enlarged by 150%. The structures corresponding to the area delimited for the calculation of the total, cortical, and medullary volumes are indicated in part B. (C-E) Midfemoral volume normalized by body weight. There is no significant difference between the groups. Abbreviations: CL, control; NPL, nonparetic; PL, paretic.*

early mobilization and protocols, which establish community activities such as walking and recreational activities, and preventing falls in acute and chronic periods, should be prescribed to prevent bone mineral loss. In addition, strategies to reduce asymmetries and compensations and to prevent the disuse are important.

Despite these considerations, it is important to highlight that this work presented an unprecedented approach on the importance of the inclusion of bone health in the studies of chronic hemiparetic subjects. In addition, the present study contemplated the need to select specific regions for bone measurement and the identification of alternative

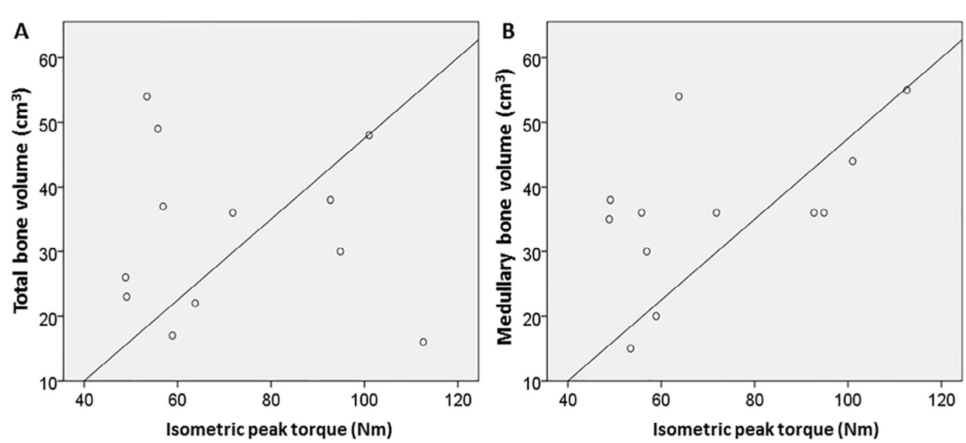

Figure 3. *Bone volume and torque correlation. (A) Correlation between the total bone volume and the maximum isometric peak torque flexion (*R = .7, P = .01*). (B) Correlation between the medullary bone volume and the maximum isometric peak torque (*R = .65, P = .03*) during flexion.*

methods of measurement to contribute to the prevention of comorbidities in this population. Even so, this work draws attention to the importance of the nonparetic limb in the rehabilitation process in a critical way.

Conclusions

Chronic hemiparetic subjects require maintenance of bone geometry compared with healthy volunteers. Correlation between midfemoral bone volume structures and isometric knee torque was possible. The nonparetic knee flexion was correlated with total and medullary bone volume.

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