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Muscle strength is a determinant of bone mineral content in the hemiparetic upper extremity: Implications for stroke rehabilitation

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Abstract

Individuals with stroke have a high incidence of bone fractures and approximately 30% of these fractures occur in the upper extremity. The high risk of falls and the decline in bone and muscle health make the chronic stroke population particularly prone to upper extremity fractures. This was the first study to investigate the bone mineral content (BMC), bone mineral density (BMD) and soft tissue composition of the upper extremities and their relationship to stroke-related impairments in ambulatory individuals with chronic stroke (onset >1 year). Dual-energy X-ray absorptiometry (DXA) was used to acquire total body scans on 56 (22 women) community-dwelling individuals (≥50 years of age) with chronic stroke. BMC (g) and BMD (g/cm^2), lean mass (g) and fat mass (g) for each arm were derived from the total body scans. The paretic upper extremity was evaluated for muscle strength (hand-held dynamometry), spasticity (Modified Ashworth Scale), impairment of motor function (Fugl-Meyer Motor Assessment) and amount of use of the paretic arm in daily activities (Motor Activity Log). Results showed that the paretic arm had significantly lower BMC (13.8%, $p<0.001$), BMD (4.5%, $p<0.001$) and lean mass (9.0%, $p<0.001$) but higher fat mass (6.3%, $p=0.028$) than the non-paretic arm. Multiple regression analysis showed that lean mass in the paretic arm, height and muscle strength were significant predictors ($R^2=0.810$, $p<0.001$) of the paretic arm BMC. Height, muscle strength and gender were significant predictors ($R^2=0.822$, $p<0.001$) of lean mass in the paretic arm. These results highlight the potential of muscle strengthening to promote bone health of the paretic arm in individuals with chronic stroke.

Keywords

Cerebrovascular accident; rehabilitation; osteoporosis; exercise; muscle

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Introduction

Individuals with stroke have a higher risk of bone fractures than the reference population [1–3]. Of these fractures, 27–36% occur in the upper extremity [1,3]. Decreased use of the paretic upper extremity due to various impairments such as muscle weakness, spasticity and reduced motor skills may lead to secondary complications, such as bone loss and muscle atrophy [4–9]. In addition, individuals with stroke also have a higher risk of falls than the age-matched population [10]. Stroke impairments such as poor balance [11–13], reduced mobility [11] and reduced motor control [12] are some of the factors associated with high risk of falls. Decrease in bone and muscle health, as well as increase in falls, may contribute to the greater upper extremity fracture risk in individuals with stroke.

Among individuals with stroke, those who are in the chronic stage of recovery (onset>1 year) warrant particular attention, for several important reasons. First, Jorgensen and Jacobsen [5] have previously reported that those with severe impairment in the paretic arm had an average of 7% and 25% of decrease in proximal humerus bone mineral density (BMD) at 2 months and 1 year post-stroke, respectively, indicating a progressive trend of decline in BMD within the first year post-stroke. Upper extremity bone health may continue to deteriorate beyond 1 year post-stroke and further increase the risk of upper extremity fractures. Second, a large proportion (80%) of chronic stroke survivors are independent ambulators [14]. As most falls occur during walking [10–11], these individuals may have a higher risk for falls and hence, bone fractures. Third, the majority of fractures occur in the chronic stage of recovery. For example, Ramnemark et al. [3] found that the median time between stroke onset and first fracture was 2.4 years. Therefore, studying bone upper extremity health in this important group of individuals with stroke has significant clinical relevance.

Only a few studies have examined upper extremity bone health in the chronic stroke population (onset> 1 year) [15–20] and the results are inconsistent. For example, Hamdy et al. [20] reported a significant 12.36% side-to-side difference in total arm bone mineral density (BMD) using dual photon absorptiometry in 15 subjects (mean post-stroke duration=9.3 years). In contrast, Sahin et al. [17] reported no significant side-to-side difference in BMD of the radius using dual-energy X-ray absorptiometry (DXA) in 30 subjects (mean post-stroke duration=1 year). Sahin et al. [17] also found no correlation between the degree of paralysis and radius BMD whereas Iwamoto et al. [16] found a significant correlation between the degree of paralysis and second metacarpal BMD (measured by X-ray densitometry) in 72 subjects (mean post-stroke duration=19.4 months). The different methodologies (i.e. sample size, inclusion criteria, measurement tools and sites) used in different studies may contribute to the discrepancies in results. To date, no study has examined the bone mineral levels and soft tissue composition of the upper extremities and their relationship to stroke-related impairments in community-dwelling, ambulatory individuals with chronic stroke. Identification of the modifiable factors that influence upper extremity bone mass is important because it is key to developing effective treatment to improve bone health in this group.

We studied ambulatory, older individuals with chronic stroke to determine (1) bone mineral content (BMC), BMD and soft tissue composition in both upper extremities and (2) their relationship to muscle strength, spasticity, and the amount of use of the paretic arm in daily activities. Comparing the paretic and non-paretic limbs provides us an opportunity to examine the effects of stroke-related impairments on bone mineral levels and soft tissue composition. The total arm BMC and BMD was evaluated to provide an overall measure of the bones that comprise the upper extremity.

Materials and methods

Sample size calculation

The computer program G Power was used to calculate the sample size required for multiple regression analyses [21]. If up to 8 variables were modeled at an effect size=0.35 (large) at an alpha level of 0.05 and power of 0.80, a minimum of 52 subjects are required.

Subjects

Community-dwelling individuals with stroke were recruited on a volunteer basis. All subjects had to fulfill the following inclusion criteria: (1) had one single stroke only, (2) had a post-stroke duration of one year or more, (3) were independent in ambulation with or without an assistive device for at least 10m, (4) were 50 years of age or older, and (5) were living at home. Potential subjects were excluded if they (1) had other neurological conditions in addition to stroke, (2) had significant musculoskeletal conditions (i.e. amputations, total shoulder replacements), (3) had unstable cardiovascular disease, (4) had a Folstein Mini Mental Status Examination (MMSE) score <22 [22], (5) had any metal implants in the upper extremities or (6) were taking prescribed medications that affect bone metabolism. Eligible subjects gave informed, written consent to participate in the study. Written permission was also obtained from the primary care physician. The study was approved by local research ethics committees. The study was conducted according to the Helsinki Declaration for human experiments [23].

Dual-energy X-ray Absorptiometry

Each subject underwent a total body scan using dual-energy X-ray absorptiometry (DXA; Hologic QDR 4500, Hologic Inc., Waltham, MA, USA). All scans were performed by the same technician using standard procedures as described in the Hologic Users Manual. The total arm BMC (g) and BMD (g/cm^2), lean mass (g) and fat mass (g) were determined by the region of interest (ROI) program. In terms of the precision of our DXA scanner, the coefficients of variation (CV) for the left arm BMC, BMD, lean mass and fat mass were 1.0%, 0.7%, 1.2%, 3.2% respectively. The corresponding CV for the right arm were 1.0%, 1.1%, 1.1% and 5.7% respectively.

Arm Muscle Strength

Muscle strength of the paretic arm is often reduced in individuals with stroke[24–25]. As bone formation is stimulated by muscle forces [26–27], muscle strength may be a key factor affecting bone mineralization in the stroke population. Hand-held dynamometry (Nicholas MMT, Lafayette Instruments, Lafayette, IN, USA) was used to assess muscle strength in both upper extremities. It is a reliable method of testing muscle strength in individuals with stroke [28]. Subjects were instructed to sit upright in a chair with back support. Isometric strength of 4 different muscle groups was tested: (1) shoulder flexors, (2) shoulder abductors, (3) elbow flexors and (4) elbow extensors. The testing positions were standardized across subjects. To test shoulder flexors and abductors, the arm was held straight by the side of the trunk with 0 degrees of shoulder flexion and abduction. To test elbow flexors, the shoulder position was the same but the elbow was flexed at 90 degrees. To test elbow extensors, the arm was placed horizontally in front of the subject with both the shoulder and elbow joints flexed at 90 degrees. In order to obtain a better estimate of the force generated by each tested muscle, 3 maximal isometric contractions of each muscle group were performed with a brief rest between contractions (30s) and the data were averaged. The mean force values of the 4 muscle groups on one side were summed to obtain the composite muscle strength score for each arm.

Impairment level

The Fugl-Meyer Motor Assessment was used to evaluate the severity of impairment in the paretic upper extremity. It was based on the performance of 33 tasks, which assess the quality of movements, reflex activity and coordination. A score from 0 to 2 was given to each task, with a higher score indicating better performance (maximum score=66). It is a reliable and valid measure of multijoint upper extremity function in stroke [29–31].

Spasticity

Spasticity adversely affects arm function and may therefore have an impact on bone health of the paretic arm. The Modified Ashworth Scale was used to assess resistance to passive movements in the elbow and hand on the paretic side (0: no increase in muscle tone, 4: affected part rigid in flexion and extension). The scores for the elbow and hand were averaged. The Modified Ashworth Scale is a reliable tool to assess upper extremity muscle tone in individuals with stroke [32].

Amount of use

More frequent use of the paretic arm is associated with more frequent activation of the paretic arm muscles, which may help stimulate bone formation. The amount of use scale in the Motor Activity Log was used to evaluate how much a person used the paretic upper extremity [33]. It was a questionnaire consisting of 30 functional tasks (e.g. putting on shoes, opening a drawer). Subjects were asked to indicate how much they used the paretic arm in each of functional tasks with a score from 0 to 5 for each item (0: paretic arm not used; 3: paretic arm used about half as much as before the stroke; 5: paretic arm used as much as before the stroke). The scores for the 30 items were averaged to obtain a mean score. The Motor Activity Log has been shown to have high internal consistency and reasonable construct validity [34].

Statistical Analysis

Paired t-tests were used to examine whether there were side-to-side differences in total arm BMC, BMD, lean mass, and fat mass. Normal distribution of different variables was tested by Kolmogorov-Smirnov test of normality. Pearson's moment correlations were used for nominal data that were normally distributed: (1) paretic arm BMC, (2) paretic arm BMD, (3) paretic arm lean mass, (4) paretic arm composite muscle strength score, (5) age, and (6) height. Spearman's rho correlations were used for ordinal variables or data that were not normally distributed: (1) Fugl-Meyer score, (2) spasticity, (3) amount of use score, and (4) post-stroke duration. A point-biserial correlation was used to quantify the relationship between gender (dichotomous variable; male=0, female=1) and other variables.

Stepwise multiple regression analyses were performed to identify significant predictors of paretic arm BMC. A predictor was entered into the model at $p \le 0.05$ and was removed at $p > 0.1$. All statistical analyses were performed using SPSS11.5 software (SPSS Inc.) using a significance level of 0.05 (2-tailed).

Results

Subject characteristics

Sixty three subjects (36 men, 27 women) volunteered to participate in the study. A total of 7 people were eventually excluded from the study. Of these, 5 people (1 man, 4 women) were taking prescribed medications that affect bone metabolism; 1 man had a shoulder hemiarthroplasty and 1 woman had severe spasticity in the paretic upper extremity that positioning for the DXA scan could not be attained. As a result, the data from 56 community-dwelling individuals with chronic stroke (34 men, 22 women) were included. Subject characteristics are listed in Table 1. Seventeen subjects used an assistive device (wheeled walker, n= 5; crutch, n=1; quad cane, n=3; cane, n=8) and 9 subjects used an ankle foot orthosis for ambulation.

Comparison of bone mineral levels and soft tissue composition between arms

Bone mineral levels and soft tissue composition were significantly different between the two arms (Table 2). The paretic arm had a significant 13.8% ($p<0.001$) and 4.5 % ($p<0.001$) lower BMC and BMD, respectively when compared to the non-paretic arm. In terms of soft tissue composition, lean mass was significantly lower (9.0%, $p<0.001$) but fat mass was significantly higher (6.3%, $p=0.025$) in the paretic arm than in the non-paretic arm.

Stroke-specific impairments and bone mineral levels

Paretic arm BMC was significantly correlated with muscle strength, height, gender and paretic arm lean mass (Table 3). These correlated variables were then entered into the first stepwise multiple regression model to predict paretic arm BMC (Table 4, regression model 1). Analysis showed that paretic arm lean mass was the most important predictor of paretic arm BMC, accounting for 73.5% of its variance. Adding height and muscle strength accounted for an additional 3.4% and 4.1% of the variance, respectively [$F(3,52)=74.030$, $p<0.001$]. Gender, on the other hand, was removed from this model ($p>0.1$).

The first regression model may have underestimated the effects of paretic arm muscle strength on BMC due to its moderate correlation with lean mass ($r=0.542$, $p<0.001$), which turned out to be the best predictor of paretic arm BMC. Using muscle strength rather than lean mass to predict paretic arm BMC may be more practical for clinicians. Hand-held dynamometry is an inexpensive and easy instrument to evaluate muscle strength and is readily accessible in most clinical settings. Thus, only paretic arm muscle strength, gender and height were entered into the second regression model. In this model, height was a major predictor of paretic arm BMC, accounting for 65.4% of its variance. After controlling for height, paretic arm muscle strength was the second important predictor of paretic arm BMC, accounting for 11.7 % of its variance. Adding gender only accounted for an additional 2.9% of the variance in paretic arm BMC [$F(3,52)=69.495$, $p<0.001$].

Stroke-specific impairments and muscle atrophy

Paretic arm lean mass was significantly correlated with paretic arm muscle strength, height, and gender (Table 3). These correlated variables were then entered into the third multiple regression model to predict paretic arm lean mass (Table 4, model 3). Height was a strong predictor of paretic arm lean mass, accounting for 67.4% of its variance. Muscle strength was also a significant predictor of paretic arm lean mass, accounting for 7.7% of its variance. Adding gender accounted for an additional 7.1% of the variance in paretic arm lean mass [$F(3,52)=79.960$, $p<0.001$].

Discussion

Pronounced side-to-side difference of bone mass in chronic stroke

The effect of stroke on bone demineralization could be examined by comparing the bone mineral levels between the paretic and non-paretic arm. We reported a large difference (13.8%) in BMC between the paretic and non-paretic arm in older individuals with chronic stroke. Our finding is thus comparable to Iversen et al. [35] who reported a 10.3% side-to-side difference in total arm BMC using single photon absorptiometry in 15 subjects who had a post-stroke duration of 23–38 weeks. Hamdy et al. [20] reported a higher difference in BMC between the two arms (21.78%) using dual photon absorptiometry in a sample of 15 subjects with chronic stroke (mean onset=484 weeks). The higher degree of bone loss may be explained by the more severe motor paralysis in their sample (71% side-to-side difference in arm muscle strength) compared to our sample (32.5% side-to-side difference).

The observed side-to-side difference in bone mineral levels is much higher than those observed between the dominant and non-dominant arm in non-athletic individuals who did not participate in activities that involved the dominant arm only. Generally less than 5% side-to-side difference in BMC was reported in various sites of the upper extremity (i.e. proximal humerus, humeral shaft, radial shaft and distal radius) in these individuals [36–39]. Taaffe et al. [40] examined the effect of hand preference on upper limb bone mineral levels in elderly women. They found a significant but small difference in total arm BMC (4.2%) and BMD (1.0%) between the dominant and non-dominant side, well below what was observed in this study. Thus, hemiparesis caused by stroke has pronounced effect on bone demineralization in the paretic arm.

In a sample of 19 subjects (11 ambulatory), Ramnemark et al. [7] reported a 7.6% decrease in the total arm BMD and 3.6% increase in non-paretic arm BMD within the first year post-stroke. The increased activity performed by the non-paretic arm may have accounted for the increase of BMD in the non-paretic arm. Therefore, it is possible that the large side-to-side difference in BMC observed in our subjects could be attributable to both disuse of the paretic arm and, to a lesser extent, increased activity performed by the non-paretic arm in individuals with chronic stroke.

Apart from bone mineral levels, the soft tissue composition of the paretic arm was also different from the non-paretic arm. We showed that the paretic arm had a significant 9.0% lower lean mass than the non-paretic arm, comparable to the values reported in individuals with chronic stroke (6.3–12.0%) [8,35]. The side-to-side difference in lean mass reported in this study was higher than previously reported in healthy elderly women (4.2%) [40]. In terms of fat mass, a 6.3% side-to-side difference was observed in our sample. Results were inconsistent in previous studies. Iversen et al. [35] reported a large side-to-side difference (15%) in a sample of 15 stroke patients (onset=23–38 weeks) whereas Ryan et al. [8] found no significant difference between the two arms in 60 subjects (onset=3 years). However, the degree of motor paralysis or functional status of the paretic arm was not reported in these studies and thus meaningful comparisons could not be made. Nevertheless, significant muscle atrophy is apparent in the paretic upper extremity. This is not surprising, given that the composite arm strength on the paretic side was only 67.5% of the non-paretic side, indicating moderately severe paralysis of the paretic arm.

Predictors of bone mineral content in paretic arm

Paretic arm lean mass and muscle strength were important predictors of total arm BMC, indicating that those with muscle atrophy and muscle weakness tended to have low bone mass in the paretic arm. Muscle weakness is a major impairment in stroke [24–25]. In addition to the observed reduction in lean mass, other factors such as the decrease in central drive [41], the reduction in the number of functioning motor units [42–43], and changes in motor unit recruitment and discharge rate [44–46], may adversely affect the ability to voluntarily generate force on the paretic side. Sufficient mechanical forces required for stimulating bone formation are thus lacking, which eventually leads to bone loss [26].

The importance of muscle strength in upper extremity bone health has been highlighted in other populations. For example, upper extremity muscle strength was significantly correlated with radial BMD in osteoporotic men [47], older men [47] and post-menopausal women [48]. Hand grip strength was an independent predictor of distal radius BMC [49] and metacarpal BMD in postmenopausal women [50].

Although one might expect that more frequent use of the arm would result in a higher BMC or lean mass, the amount of use was not correlated with either the paretic arm BMC or lean mass. One of the explanations would be that the 30 functional tasks included in the Motor Activity Log were predominantly light functional activities, which did not require a high level of arm muscle strength for their successful execution. Therefore, more frequent use of the paretic arm to perform these daily functional activities may not produce sufficient mechanical loading to fully counteract the bone demineralization due to hemiparesis.

It is interesting that upper extremity motor impairment (i.e., Fugl-Meyer score) was not correlated with paretic arm BMC or BMD. The tasks in the Fugl-Meyer Motor Assessment mainly assessed specific movement patterns and reflex activity. Similar to the Motor Activity Log, it did not require the subject to generate a high level of muscle force to perform the tasks.

Bone mineral levels in the upper extremity normally decline with age [51]. However, we did not find such a correlation in our study. The total arm BMC was also not related to the post-stroke duration. These findings suggested that severity of stroke was more important than age and post-stroke duration in determining the paretic arm BMC.

Clinical implications

The results of this study suggest that increasing or maintaining muscle mass and muscle strength may be important in promoting bone health of the paretic upper extremity in individuals with chronic stroke. Thus, strengthening exercises may be a useful treatment method to maintain or improve bone mass in this group. There is some evidence that upper extremity strengthening exercises are effective in enhancing bone health in older populations. For example, Kerr et al. [52] found in postmenopausal women that BMD at the ultradistal radial site was increased following a 1-year strength training program. A 6-month strengthening program designed to maximize the stress on the wrist also increased the cortical BMC at ultradistal radius in postmenopausal women [53].

Unfortunately, strength training has not been a universally accepted practice in stroke rehabilitation. Bobath [54] maintained that motor dysfunction seen in persons with stroke was not due to muscle weakness but to the emergence of abnormal movement patterns. Moreover, it was held that effortful activities would increase spasticity and reinforce these abnormal movements [54]. However, recent research findings have disputed this notion. No increase in spasticity was observed in individuals with stroke who underwent intensive strength training [55–56].

Research is limited in examining the effects of upper extremity strength training in stroke. Improvements in upper extremity muscle strength following a strength training program have been reported by Butefisch et al. [57] and Bourbonnais et al. [58]. However, no study has investigated whether upper extremity muscle strengthening is beneficial in increasing or maintaining paretic arm bone mass in the stroke population. Further study will be required to address this important research question.

Limitations

We used DXA to measure bone mineral levels and lean mass. Its accuracy for bone mineral measurement has been validated [59]. Its reproducibility in the upper extremity of individuals with stroke has also been shown [60]. However, DXA has several limitations. It is unable to assess bone geometry due to its planar nature. Areal BMD only partially accounts for the fact that wider bones are also deeper and thus tends to overestimate the gender-specific differences in bone density due to larger bones in men [61]. Therefore, we used BMC in our regression analysis because it measures the absolute amount of bone minerals and gender and height were factors in the models. However, the results were similar if BMD was used as the dependent variable in these models. In addition, lean mass measurements by DXA can be affected by the state of hydration [62]. Overestimation of muscle mass in the paretic leg may occur since swelling in the paretic arm is quite common in individuals with stroke [63]. However, we showed that the paretic leg had a substantially lower lean mass than the non-paretic leg. Thus this possible artifact cannot explain our results.

Conclusion

We have shown that the paretic arm has substantial bone loss and muscle atrophy in community-dwelling, ambulatory individuals with chronic stroke. This is the first study to show that muscle mass and muscle strength of the paretic arm were important predictors of its bone mass in this group of individuals. Exercises to increase muscle mass and strength of the paretic arm may be beneficial in promoting bone mass of the paretic arm in this group. The effectiveness of upper extremity strength training on increasing paretic arm bone mass requires further study.

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Table 1

Subject Characteristics

Variable	Mean±SD
Subject demographics	
Gender (male/female)	34/22
Paretic side (left/right)	36/20
Hand dominance (left/right)	3/53
Race (White/Asian/Black)	35/20/1
Post-stroke duration (years)	5.2±4.1
Age (years)	65.4±8.9
Mass (kg)	77.5±15.8
Height (cm)	169.3±10.7
Stroke-specific impairments	
Composite Arm Strength Score (N)	
Paretic arm	186.4±110.0
Non-paretic arm	289.0±107.9
Spasticity (median)	0.5
Fugl-Meyer score	47.0±19.6
Amount of Use Score	2.5±1.8

Table 2

Comparison between paretic arm and non-paretic arm

Variable	Paretic arm	Non-paretic arm	Difference between arms (%)	p (paired-t tests)
Total arm BMC, g	148.87±52.74	173.14±55.32	13.8	<0.001
Total arm BMD, g/cm^2	0.75±0.14	0.78±0.12	4.5	<0.001
Lean mass, g	2625.73±845.43	2922.83±955.61	9.0	<0.001
Fat mass, g	1395.24±602.77	1339.25±621.80	6.3	0.028

Table 3

Correlations with paretic arm BMC, BMD, lean mass and fat mass

Variables	BMC	BMD	Lean mass	Fat mass
Composite Arm Muscle Strength Score	0.599**	0.426**	0.542**	0.015
Fugl-Meyer score	0.103	−0.032	−0.022	0.108
Spasticity	−0.197	−0.068	−0.037	0.217
Amount of use	−0.019	−0.107	−0.118	−0.161
Height	0.809**	0.735**	0.821**	−0.173
Age	−0.034	−0.058	−0.140	−0.054
Post-stroke duration	0.056	−0.003	0.089	0.260
Gender	−0.711**	−0.732**	−0.785**	0.226
Lean mass	0.857**	0.744**	—	−0.009
Fat mass	−0.070	−0.213	−0.009	—

* $p<0.05$,

** $p<0.005$

Table 4

Multiple regression analysis for predicting paretic arm BMC and lean mass

Dependent variable	Predictors	R^2	R^2 Change	β	p for each predictor
1. Paretic arm BMC[a]	Paretic arm lean mass	0.735	0.735	0.593	0.002
	Height	0.769	0.034	0.323	0.001
	Muscle strength	0.810	0.041	0.247	0.001
2. Paretic arm BMC	Height	0.654	0.654	0.490	<0.001
	Muscle strength	0.771	0.117	0.370	<0.001
	Gender	0.800	0.029	−0.257	0.008
3. Paretic arm lean mass	Height	0.674	0.674	0.415	<0.001
	Muscle strength	0.750	0.077	0.304	<0.001
	Gender	0.822	0.071	−0.403	<0.001

[a] Excluded variables: gender