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ORIGINAL ARTICLE

# Relationship between physical activity, lean body mass, and bone mass in the Mexican adult population

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## Abstract

*Summary* We evaluated the association between leisure-time physical activity (LTPA), bone mineral content (BMC), and lean mass (LM) in whole body (wb) and limbs of the Mexican adult population. Our results demonstrate that some types of LTPA with relatively high/medium impact on bones such as football, basketball, tennis, and weightlifting improve BMC and LM.

**Purpose** To evaluate the effect of different kinds of leisure-time physical activity (LTPA) on bone mass values and its association with lean mass (LM) in the whole body (wb) and limbs of a large sample of Mexican men and premenopausal (pre-MP) women.

**Methods** We conducted a cross-sectional analysis of data from the Health Workers Cohort Study. Bone mineral content (BMC, kg), bone area (cm$^2$), and LM (kg) were measured with DXA. The LTPA level and the "sedentary" condition were determined using a validated questionnaire adapted for the Mexican population. One-way ANOVA tests evaluated the differences in weight, height, body mass index, and wb, lower limb (ll) and upper limb (ul) BMC and LM between the active (those who engaged in LTPA) and sedentary group. Relationships between BMC and LM values were analyzed. Slopes of the curves and *Z* scores of LTPA groups with respect to the sedentary group were compared.

**Results** In men, both wb-BMC and ll-BMC were significantly higher in the groups performing basketball, football, tennis, weightlifting, and running, and all wb-LM, ll-LM, and ul-LM were higher in running, weightlifting, football, and basketball groups with respect to the sedentary group. Both the *Z* scores and the slopes of BMC-vs-LM relationships were higher than the controls, but only in the ll of male basketball and football players.

**Conclusion** Our findings demonstrate that some types of LTPA with relatively high/medium impact on bones, such as football, basketball, tennis, and weightlifting, improve both BMC and LM compared to sedentary individuals. Finally, this relationship is stronger for the bones found in the legs and it seems that women are less sensitive to this effect, possibly due to hormonal, dietary, and pharmacological reasons.

**Keywords** Bone mineral content · Lean mass · Muscle-bone interactions · Recreational physical activity

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## Introduction

Osteoporotic fractures increase with age independently of gender and race [1], having a significant impact on public health in both developed and developing countries [2]. In Mexico, people 50 years and older have a high prevalence of osteoporosis (6.0% in men and 16.0% in women for the femoral region and 9.0 and 17.0% for the lumbar spine) [3], with an estimated lifetime risk of hip fracture of 3.8 and 8.5% for men and women, respectively [4]. In 2010, the cost of osteopenia and osteoporosis was projected to be 155 million USD and estimated to increase by about 41.7% in 2050 [5]. One of the ways to prevent this condition is by acquiring high bone mass in early life stages, which is known to be a crucial determinant of bone mass quantity and health later in life [6] that may decrease the risk of osteoporotic fractures by 50%.

Bone structure is largely subject to significant influences from metabolic and mechanical environments. Metabolic influences are determined by several factors, including sex hormones, diet, and drug use [7, 8]. Mechanical influences consist of bone modeling with positive effects on bone geometry. Relatively greater positive effects are observed in males compared to females due to larger muscle mass and strength [9].

During the process of bone acquisition and maintenance, the mechanical environment of the skeleton affects bone strength and may also explain some differences in bone features between men and women and among active and sedentary individuals, in association with differences in body composition [10]. Physical activity has been linked to bone accretion, but this effect is related not only to muscle mass/strength gains but also to the mechanical impact exerted on bones [11, 12]. Accordingly, the mechanostat theory [13] proposes that muscle and bone must be analyzed as a linked unit [14]. Therefore, to determine the impact on the skeleton, the frequency, intensity, duration, and type of physical activity must be considered [11, 12]. In this sense, the effects of different types of common leisure-time physical activities (LTPA) which induce relatively low but highly variable degrees of impact on young-adult male and female skeletons (and hence may have some epidemiological implications concerning osteoporosis prevention) have not been completely studied.

Muscle-bone interactions can be evaluated by different methods [15, 16]. A simple DXA assessment of bone mineral content (BMC) of whole body or limbs and lean mass (LM) allows the anthropometric proportionality between bone and muscle mass to be evaluated. In healthy individuals, the BMC-vs-LM relationship may vary proportionally depending on the degree of impact and the use of comparable regional muscle masses. This aspect of muscle-bone interactions can be evaluated by *Z* scoring the corresponding relationships in whole body or limbs, as we have shown in large samples of Argentine and Colombian individuals [17]. We were among the first research teams to (1) emphasize the relevance of muscle mass, force, and use of biological determination of bone mechanical properties [13, 18, 19]; (2) describe the DXA-assessed BMC-vs-LM relationships in male and female humans of all ages, interpreting the observed sex-related differences emerging after puberty and after menopause (MP) from an evolutionary perspective [20]; and (3) show that the *Z* scores of the BMC-vs-LM relationships reflect a crucial aspect of the development of bone frailty and fracture risk in post-MP osteoporotic women [21].

To complement our previous investigations, this study evaluates the DXA-assessed BMC and LM values and the BMC-vs-LM relationships of the whole body and limbs of a large sample of healthy Mexican men and pre-menopausal (pre-MP) women. A portion of these individuals performed many types of LTPA with different levels of impact induced on the skeleton, while others were inactive. The goal was to establish as follows: (1) whether the method is or is not able to detect differences in the effects of each physical activity on bone mass values and the muscle-bone relationship, compared to the inactive individuals, and if so, (2) whether the differences are or not associated with the different impact that every discipline is known to exert on specific regions of the skeleton, and (3) if the effects are or not region- and/or sex-dependent.

## Methods

In this cross-sectional analysis, we analyzed data from the Health Worker Cohort Study (HWCS); design and methodology have been detailed elsewhere [22]. The HWSC is a prospective study of health professionals and their relatives who were enrolled between 2004 and 2006. A total of 10,769 participants aged 7–89 years were originally recruited from three collaborating centers in two states of Mexico [23].

For the present analysis, we excluded subjects under 20 years and over 51 years for women ($n = 1836$), those with incomplete or missing body composition information ($n = 1178$), and those with incomplete or missing physical activity data ($n = 584$). Individuals were also excluded from the final analysis if their weight was ≥ 120 kg and if both sides of their body were incompletely scanned (e.g., they were too large) ($n = 68$). We also excluded those with type 2 diabetes mellitus, rheumatoid arthritis, cirrhosis, chronic kidney disease, asthma, degenerative arthritis, hepatitis, hip or femur fracture, or osteoporosis. A total of 4116 apparently healthy individuals (1488 men and 2628 women) were included in our final analysis.

We classified men and pre-MP women according to their type and level of physical activity. Nine groups of comparable ages were distinguished within each sex according to the type of LTPA they had performed (Tables 1 and 2). Those who reported not practicing any type of LTPA (including walking) other than domestic activities were assigned to a separate group. The "sedentary" group was noted as a control for the study.

As we reported previously [23], the ethics committees of all participating institutions reviewed and approved the study protocol and informed consent forms. In addition, informed consent was obtained from all individual participants included in the present study. Finally, the present study was performed according to the Declaration of Helsinki guidelines.

## Measurements

### Leisure-time physical activity

Leisure-time physical activity (LTPA) was measured using a validated questionnaire, which was adapted for the Mexican urban population by adding specific activities that are commonly practiced in the country and eliminating others that are performed less frequently [24]. Individuals reported the frequency (days/week), volume (hours/week), and intensity of activities carried out during a typical week in the last year, which were categorized as "light" (comparable to normal walking), "moderate" (enough to provoke some sweating), or "vigorous" (training in some sport at a competitive level). Physical activities were considered for study when performed with a "moderate" intensity during no less than 3 h per week. Physical activities comprised walking, running, bicycling, softball, football, volleyball, aerobics, dance, bowling, "pelota," swimming, tennis, basketball, and squash. The degree of LTPA was estimated by adding up the values for the individual activities (considering time and frequency). As a gross estimation of the volume of performed activities, metabolic equivalents (MET) values per week were calculated for every individual [25] as the product of the duration and intensity of the corresponding activity. Results were expressed with reference to a specific index assigned to each discipline. This index was adjusted according to body mass for each sex.

### Body composition measurement

The BMC and LM (kg) were determined in the whole body and upper and lower limbs of every individual after a 12-h fasting period. The remaining measures were taken with a Lunar DPX NT instrument by trained personal using standardized procedures. Precision value (CV) was 1.0% for all measurements [22].

### Anthropometric measurements

Weight and height were assessed according to Lohman et al. [26]. Body weight was measured with a calibrated electronic scale (BC-533 model; Tanita) with barefoot participants wearing minimum clothing. Height was measured using a conventional stadiometer (SECA), with barefoot participants standing with their shoulders in a normal position at maximal inspiration. Body mass index (BMI) was calculated as usual [27]. Concordance coefficients between 0.83 and 0.90 for the anthropometric measurements were achieved [22].

### Statistical analyses

Standard, one-way ANOVA tests were conducted to evaluate the differences in weight, height, BMI, whole body BMC (wb-BMC), lower limb BMC (ll-BMC), upper limb BMC (ul-BMC), BMC index ($\mathrm{BMCI} = \mathrm{wbBMC/heigth}^2$), whole body LM (wb-LM), lower limb LM (ll-LM), upper limb LM (ul-LM), and LM index ($\mathrm{LMI} = \mathrm{LM/heigth}^2$) between LTPAs and control groups.

Correlations between the BMC ($y$) and LM ($x$) of the whole body and upper and lower limbs of the control groups of men and pre-MP women were analyzed. The (always linear) regression lines and 6 additional parallel, equidistant lines representing the $+1, +2, +3, -1, -2$, and $-3$ SD ($+1, +2, +3, -1, -2$, and $-3$ $Z$ score) limits for the dispersion of the data were indicated in each graph as normal references.

The same BMC-vs-LM relationships were calculated for each of the LTPA groups. Then, using the BMC-vs-LM relationships of control men and women as references, individual $Z$ scores were calculated for every LTPA group. The calculated individual $Z$ scores represented standardized measurements of variation derived from dividing the difference between every individual's BMC datum ($X$) and the corresponding men/women control BMC value ($\mu$) times the BMC value of the control group SD ($\sigma$) corresponding to the same LM value, as

$$Z = X - \mu/\sigma$$

The calculated $Z$ scores of every LTPA group were then compared with those of male or female controls and the differences were tested by one-way ANOVA. Simple correlation and regression analyses tested the associations between wb-BMC vs wb-LM, ll-BMC vs ll-LM, and ul-BMC vs ul-LM of every group. ANCOVA tests evaluated the slope and intercept differences between the regression curves. $P < 0.05$ values were considered statistically significant. All statistical analyses were conducted using STATISTICA (version 8.0, 2008: StatSoft, Inc., USA).

**Table 1** Main characteristic of the study population among men

| Men | Sedentary | Cycling | Aerobics | Swimming | Walking | Running | Weightlifting | Tennis | Football | Basketball |
|---|---|---|---|---|---|---|---|---|---|---|
| *N* | 364 | 76 | 37 | 51 | 264 | 273 | 24 | 33 | 319 | 45 |
| Age (years) | 45.8 ± 14.1 | 43.9 ± 12.0 | 43.4 ± 17.1 | 43.7 ± 13.8 | 50.3 ± 15.9 | 40.9 ± 11.4 | 38.8 ± 10.7 | 45.8 ± 10.7 | 36.1 ± 10.2 | 34.8 ± 10.7 |
| Total mets/week | 119 ± 55 | 155 ± 68** | 163 ± 61** | 137 ± 49 | 134 ± 56 | 160 ± 70** | 183 ± 80** | 179 ± 69* | 182 ± 70*** | 182 ± 70*** |
| Weight (kg) | 71.58 ± 9.47 | 71.67 ± 8.01 | 72.01 ± 10.30 | 73.70 ± 9.79 | 72.05 ± 10.12 | 73.55 ± 9.05 | 74.12 ± 8.92 | 74.81 ± 10.91 | 72.69 ± 9.17 | 76.78 ± 9.94*** |
| Height (cm) | 167.5 ± 6.86 | 168.2 ± 6.23 | 166.0 ± 6.09 | 170.1 ± 6.66 | 167.9 ± 6.68 | 169.1 ± 6.52 | 169.9 ± 5.31 | 169.5 ± 7.62 | 168.9 ± 6.86 | 172.6 ± 7.49*** |
| BMI (kg/m$^2$) | 25.48 ± 2.76 | 25.41 ± 2.43 | 25.92 ± 3.17 | 25.40 ± 2.90 | 25.40 ± 2.68 | 25.70 ± 2.41 | 25.74 ± 2.20 | 26.02 ± 2.60 | 25.40 ± 2.57 | 25.76 ± 2.82 |
| BMCI (kg/m$^2$) | 0.972 ± 0.106 | 0.983 ± 0.110 | 0.953 ± 0.114 | 0.969 ± 0.096 | 0.968 ± 0.113 | 1.005 ± 0.107*** | 1.029 ± 0.104 | 1.021 ± 0.095* | 1.037 ± 0.119*** | 1.047 ± 0.137*** |
| LMI (kg/m$^2$) | 16.94 ± 1.52 | 17.24 ± 1.33 | 16.94 ± 1.60 | 16.89 ± 1.73 | 16.89 ± 1.47 | 17.30 ± 1.62 | 17.71 ± 1.71 | 16.98 ± 1.41 | 17.44 ± 1.60*** | 17.31 ± 1.57 |
| wbBMC (g) | 2733 ± 389 | 2784 ± 349 | 2645 ± 373 | 2809 ± 345 | 2740 ± 423 | 2868 ± 380*** | 2979 ± 413** | 2935 ± 369** | 2960 ± 400*** | 2130 ± 417*** |
| ll-BMC (g) | 1005 ± 157 | 1012 ± 145 | 994 ± 149 | 1030 ± 149 | 1009 ± 175 | 1068 ± 156*** | 1094 ± 154** | 1078 ± 146* | 1109 ± 170*** | 1182 ± 209*** |
| ul-BMC (g) | 391.5 ± 66.5 | 405.7 ± 69.4 | 375.3 ± 59.4 | 405.0 ± 68.0 | 387.4 ± 71.4 | 415.1 ± 69.9*** | 422.9 ± 73.9* | 414.2 ± 71.9 | 417.6 ± 65.4*** | 429.3 ± 69.5*** |
| wb-LM (g) | 47,569 ± 5510 | 48,842 ± 5018 | 47,647 ± 6033 | 48,934 ± 5986 | 47,734 ± 5578 | 49,574 ± 5688*** | 51,190 ± 6253** | 48,842 ± 5801 | 49,744 ± 5321*** | 51,694 ± 6368*** |
| ll-LM (g) | 15,681 ± 2124 | 16,022 ± 1941 | 15,568 ± 2188 | 15,985 ± 2120 | 15,625 ± 2245 | 16,416 ± 2151*** | 16,769 ± 2146*** | 16,151 ± 2463 | 16,578 ± 1969*** | 17,530 ± 2239*** |
| ul-LM (g) | 6141 ± 1027 | 6347 ± 1103 | 5943 ± 914 | 6265 ± 1141 | 6005 ± 1063 | 6527 ± 1237*** | 7039 ± 1454*** | 6340 ± 1044 | 6522 ± 939*** | 6816 ± 1127*** |

*BMI* body mass index (weight/height$^2$), *BMCI* bone mineral content index (wbBMC/height$^2$), *LMI* lean mass index (wbLM/height$^2$), *wb-BMC* whole body bone mineral content, *ll-BMC* lower limb bone mineral content, *ul-BMC* upper limb bone mineral content, *wb-LM* whole body lean mass, *ll-LM* lower limb lean mass, *ul-LM* upper limb lean mass. Statistically significant differences with respect to sedentary group: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

**Table 2** Main characteristic of the study population among premenopausal women

| Women | Sedentary | Cycling | Aerobics | Swimming | Walking | Running | Weightlifting | Tennis | Football | Basketball |
|---|---|---|---|---|---|---|---|---|---|---|
| N | 1084 | 143 | 252 | 113 | 523 | 370 | 31 | 8 | 53 | 50 |
| Age (years) | 35.9 ± 8.1 | 35.0 ± 7.8 | 33.2 ± 8.5 | 35.4 ± 8.6 | 36.6 ± 9.3 | 34.3 ± 8.0 | 36.2 ± 9.3 | 37.5 ± 5.8 | 27.6 ± 7.6* | 30.2 ± 8.0 |
| Age of menarche | 12.6 ± 1.8 | 12.5 ± 1.6 | 12.5 ± 1.4 | 12.6 ± 1.5 | 12.5 ± 1.4 | 12.6 ± 2.0 | 12.2 ± 2.0 | 12.4 ± 1.9 | 12.0 ± 2.2 | 12.1 ± 1.9 |
| Contraceptive use | | | | | | | | | | |
| Total mets/weeks | 137 ± 55 | 156 ± 62* | 172 ± 60** | 165 ± 57* | 154 ± 56* | 168 ± 64* | 170 ± 55** | 183 ± 43** | 167 ± 22*** | 171 ± 83** |
| Weight (kg) | 60.21 ± 8.07 | 59.93 ± 8.39 | 60.12 ± 8.03 | 60.64 ± 7.84 | 60.94 ± 8.33 | 59.48 ± 7.21 | 57.42 ± 6.53 | 60.38 ± 9.12 | 59.62 ± 9.58 | 59.30 ± 8.21 |
| Height (cm) | 156.19 ± 5.78 | 156.96 ± 5.81 | 156.74 ± 5.83 | 157.65 ± 5.78 | 156.43 ± 6.06 | 156.60 ± 6.19 | 159.16 ± 6.76 | 159.00 ± 6.34 | 156.60 ± 7.07 | 157.32 ± 6.93 |
| BMI (kg/m$^2$) | 24.64 ± 2.91 | 24.18 ± 2.79 | 24.46 ± 2.94 | 24.42 ± 3.13 | 24.86 ± 2.92 | 24.28 ± 2.81 | 24.45 ± 2.61 | 24.08 ± 3.11 | 24.27 ± 3.09 | 23.70 ± 3.06 |
| BMCI (kg/m$^2$) | 0.959 ± 0.101 | 0.953 ± 0.094 | 0.973 ± 0.104 | 0.960 ± 0.106 | 0.965 ± 0.092 | 0.980 ± 0.100* | 0.951 ± 0.085 | 0.971 ± 0.104 | 1.004 ± 0.112 | 0.975 ± 0.112 |
| LMI (kg/m$^2$) | 13.72 ± 1.19 | 13.67 ± 1.19 | 13.70 ± 1.21 | 13.61 ± 1.14 | 13.80 ± 1.24 | 13.89 ± 1.17 | 13.84 ± 0.97 | 13.85 ± 0.93 | 13.83 ± 1.30 | 13.94 ± 1.18 |
| wbBMC (g) | 2341 ± 299 | 2352 ± 292 | 2394 ± 312** | 2387 ± 309 | 2365 ± 293 | 2403 ± 287*** | 2413 ± 289 | 2458 ± 342 | 2464 ± 347** | 2415 ± 324** |
| ll-BMC (g) | 767 ± 109 | 778 ± 114 | 770 ± 116 | 792 ± 112 | 777 ± 121 | 793 ± 105*** | 805 ± 125 | 811 ± 112 | 817 ± 138** | 824 ± 124** |
| ul-BMC (g) | 279.7 ± 46.5 | 277.0 ± 45.4 | 283.5 ± 45.2 | 282.9 ± 52.2 | 280.0 ± 49.2 | 286.3 ± 43.4 | 296.0 ± 48.1 | 310.9 ± 46.1 | 288.8 ± 45.0 | 293.5 ± 44.6 |
| wb-LM (g) | 33,475 ± 3436 | 33,704 ± 3738 | 33,662 ± 3397 | 33,839 ± 3444 | 33,769 ± 3569 | 33,044 ± 3252** | 35,067 ± 3281** | 33,014 ± 2986 | 34,034 ± 4972 | 34,515 ± 3690 |
| ll-LM (g) | 10,683 ± 1325 | 10,879 ± 1474 | 10,906 ± 1288 | 10,823 ± 1386 | 10,780 ± 1543 | 11,031 ± 1346*** | 11,442 ± 1205** | 10,724 ± 1523* | 11,030 ± 1818 | 11,282 ± 1528*** |
| ul-LM (g) | 3739 ± 638 | 3635 ± 629 | 3726 ± 615 | 3687 ± 666 | 3733 ± 650 | 3750 ± 585 | 3878 ± 552 | 4033 ± 620 | 3787 ± 742 | 3866 ± 645 |

*BMI* body mass index (weight/height$^2$), *BMCI* bone mineral content index (wbBMC/height$^2$), *LMI* lean mass index (wbLM/height$^2$), *wb-BMC* whole body bone mineral content, ll-BMC lower limb bone mineral content, *ul-BMC* upper limb bone mineral content, *wb-LM* whole body lean mass, *ll-LM* lower limb lean mass, *ul-LM* upper limb lean mass. Statistically significant differences with respect to sedentary group: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

## Results

### Differences between mean values of every variable studied

Table 1 and Table 2 show the means and SDs of all the studied variables for each group and the statistical significance of the differences between each of the men's and women's LTPA groups and their corresponding controls. No inter-group differences were observed in age, weight, height, and BMI, except the larger weight and height observed for the male basketball group.

The MET/week values of all LTPA groups were significantly higher than those of controls, except men in the swimming and walking group. In men, MET/week values were also generally higher for weightlifting, tennis, football, and basketball groups than those shown by the other LTPA groups. In women, this difference was evident only for the tennis group.

All wb-, ll-, and ul-BMC values and the BMCI were higher in running, weightlifting, tennis, football, and basketball groups for men, except for the BMCI in weightlifters and the ul-BMC in basket players. In women, these differences were generally less or not significant.

The LM was significantly larger in running, weightlifting, football, and basketball groups of men, while LMI was significantly higher than controls only for football players. In women, the differences in LM were less significant or not at all, compared to men, and no differences were observed in LMI.

### Differences between Z scores of the BMC-vs-LM relationship

Differences between means and SDs of the *Z* score values of the BMC-vs-LM relationship of LTPAs and control (reference) groups are shown for men in Fig. 1 and for women in Fig. 2. In men, the *Z* scores were significantly higher than the reference only in the lower limbs of the football and basketball groups. In women, there were no differences

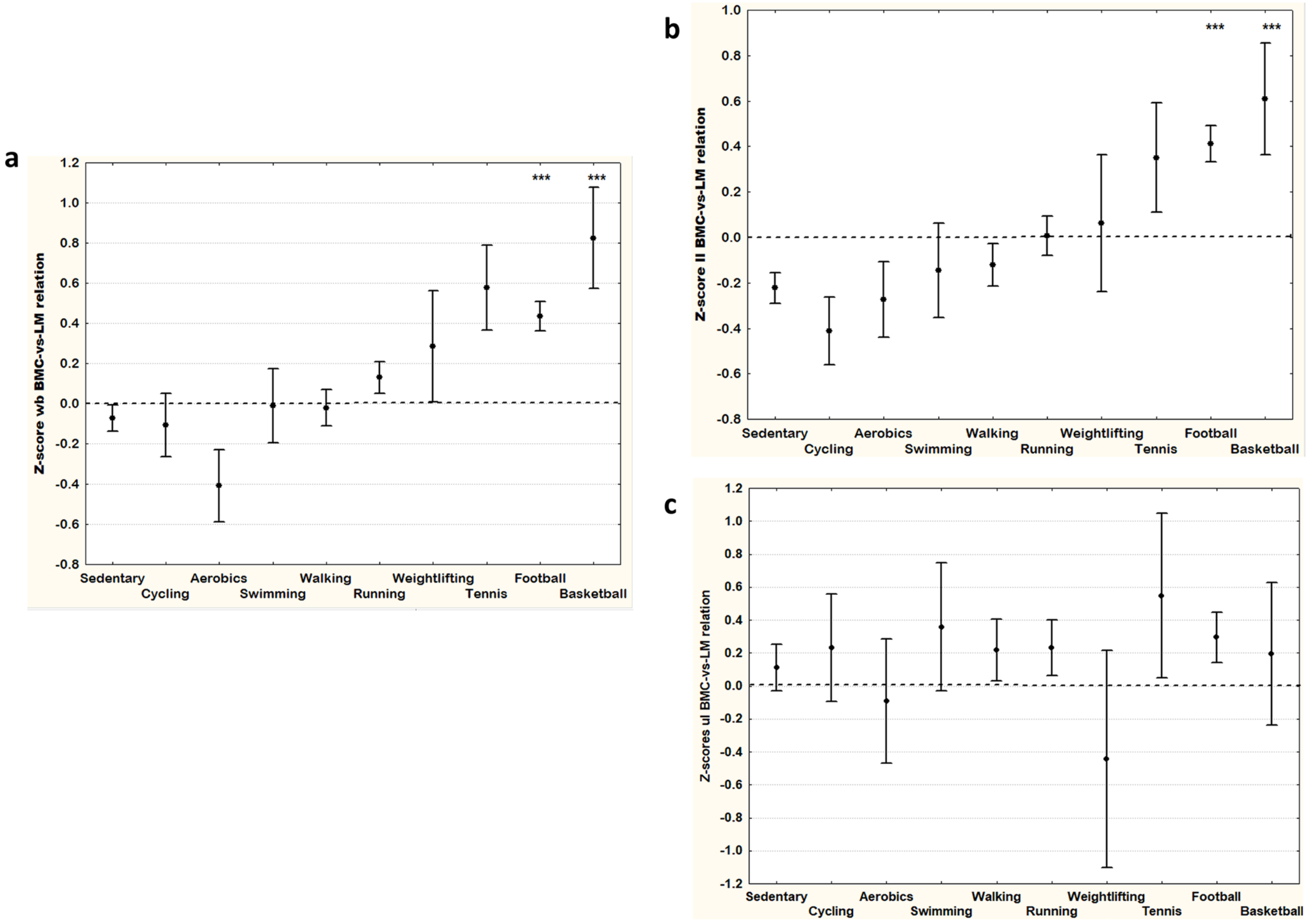

**Fig. 1** *Z* score values of the bone mineral content-lean mass relationships for all male individuals studied calculated as per the corresponding SDs of the data, discriminated by physical activities (**a**), lower limbs (**b**), and upper limbs (**c**)

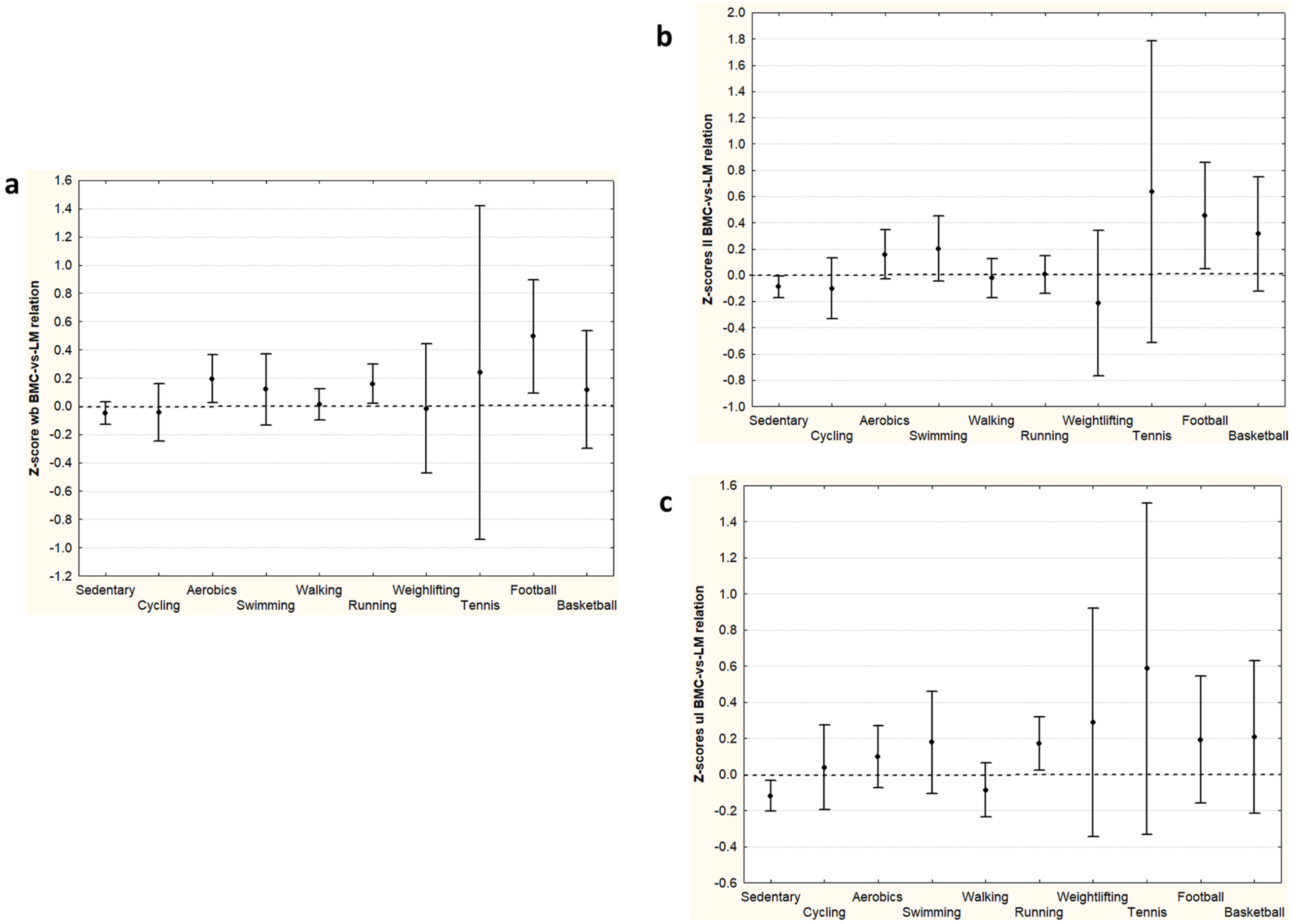

**Fig. 2** *Z* score values of the bone mineral content-lean mass relationships for all pre-menopausal female individuals studied calculated as per the corresponding SDs of the data, discriminated by physical activities (**a**), lower limbs (**b**), and upper limbs (**c**)

between the LTPA and control groups. The *Z* scores of the whole body and lower limbs of the men's groups (only—Fig. 1, graphs a & b) were progressively increasing following the order: [aerobics-cycling < swimming-walking < running < weight-lifting < tennis-football < basketball].

### Analysis of the BMC-vs-LM relationships

The BMC-vs-LM relationships for the whole body and limbs of all groups performing together are shown for men in Fig. 3 and for women in Fig. 4. In men, significantly higher slopes than those of the control groups were shown only for the football and basketball groups (not for the other LPTA groups) in the lower limbs (Fig. 3, graph B). No further significant differences were observed for any other instance of comparison in men and women. To be able to observe these results better, we graph with the same data, placing basketball, football, and the other LPTAs superimposed over the reference, *Z* scored graphs of the BMC-vs-LM relationships which were previously developed employing the control group's (men and women) data.

## Discussion

### Inter-group differences in BMC and LM values

The mechanostat theory suggests that dynamic loads are essential for bone adaptation [28]. This phenomenon is especially evident in children, adolescents, and relatively young adults [29] and is highly dependent on the degree of impact induced on bones [30] by muscle contractions and ground-reaction forces. Some sports can increase BMC at the loaded sites of the skeleton, including football and basket, as observed here [31].

Not disregarding the cross-sectional nature of the study, our findings support, in concordance with our working hypothesis, that LTPA with high or medium impacts [32, 33], such as running, football, basketball, tennis, and

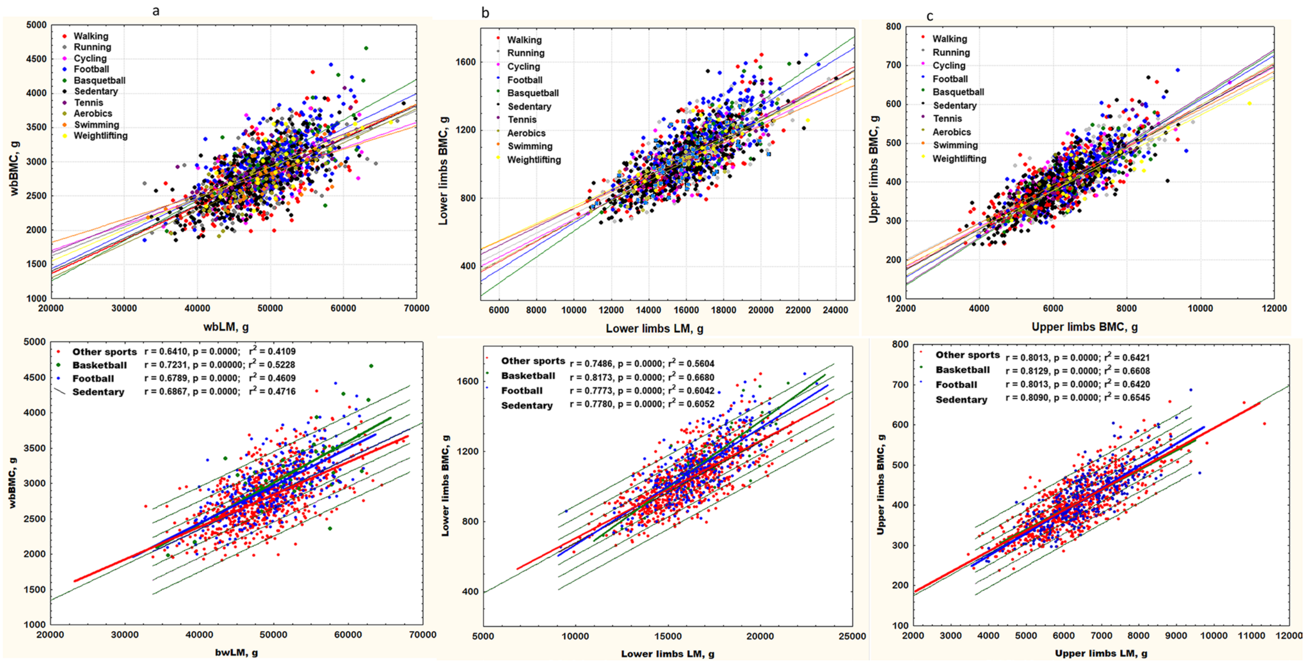

**Fig. 3** *Z* score charts of the bone mineral content-lean mass relationships for sedentary male individuals studied calculated as per the corresponding SDs of the data shown in whole body (**a**), lower limbs (**b**), and upper limbs (**c**). All figures show the data of whole body and the + 1, + 2, + 3, − 1, − 2, − 3 (in black line), and regression of football (blue), basketball (green), and other sports. ANCOVA, slope, sedentary vs football $f = 6$, $P < 0.01$, sedentary vs basketball $f = 6.5$, $P < 0.01$

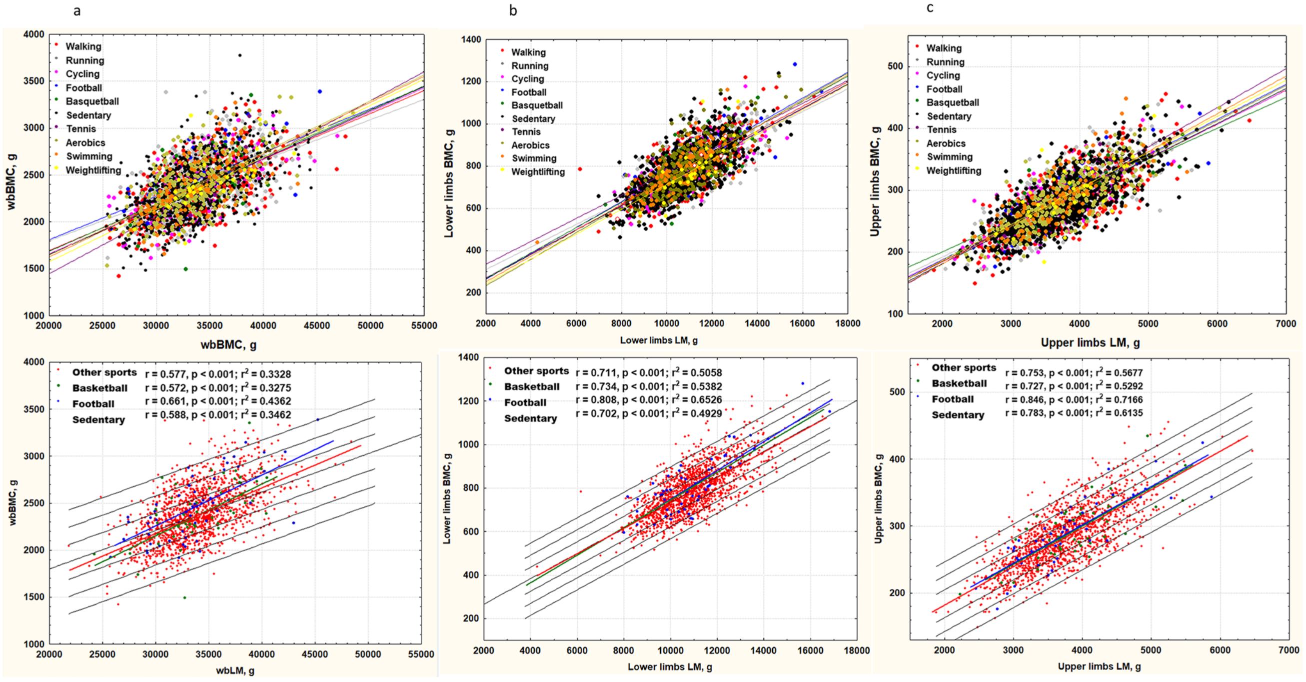

**Fig. 4** *Z* score charts of the bone mineral content-lean mass relationships for sedentary pre-menopausal individuals studied calculated as per the corresponding SDs of the data shown in whole body (**a**), lower limbs (**b**), and upper limbs (**c**). All figures show the data of whole body and the + 1, + 2, + 3, − 1, − 2, − 3 (in black line), and regression of football (blue), basketball (green), and other sports

weightlifting, improved BMC and LM in the lower (not upper) limbs in men, and basketball, football, running, and aerobics in women. Other LTPAs with low impact such as walking, cycling, or swimming did not show differences compared to the control group, in agreement with previous studies [34].

These were expected results as judged from several observations. In previous studies, our group and others have found a strong association between muscle area and bone mineral content in healthy children and adults [7, 17] and in children in different conditions [20]. High-impact exercise improved bone mass in young and middle-aged adults [35–39]. Football training improved bone outcomes compared to swimming and cycling [40, 41]. Activities that involve jumping, such as plyometrics, volleyball, and basketball increase bone mass, in contrast with low-impact sports such as swimming and cycling, which have a neutral or negative effect [34, 37, 42, 43].

### Inter-group differences and region-specificity of the BMC-vs-LM relationships

The separate BMC-vs-LM curves for high (including basketball and football), medium, and low impact LTPAs and controls showed that the BMC-vs-LM relationship was highly significant for the four groups in both sexes, in agreement with previous reports (Figs. 2 and 4) [7, 17, 44–47]. The slopes of the curves were significantly higher for basketball and football players than for other LTPAs or control groups (slope ANCOVA, $P < 0.01$) in the lower limbs, but not so in the whole body and upper limbs. As far as both football and basketball are known to exert relatively high mechanical impacts on leg bones [32, 33], these findings could mean that high impact exercise would improve the efficiency of the bone-muscle unit to optimize bone mass (design) at comparable levels of muscle mass with respect to medium or low impact activities with a high degree of region-specificity. However, no such differences were observed in pre-PM women, although it seemed as if the observed differences would have followed a similar trend.

Noteworthy, the above effects could be detected and assessed despite the relatively low volumes of the performed LTPAs as judged from the calculated MET values for every group.

### Sex effects

In general, less evident differences were observed in females compared with male participants in all instances of comparison in this study. If not derived from the lesser number of female individuals, or some weight or height differences (14), this may be due to a combination of influences which could be difficult to analyze as independent factors. One of the most relevant independent factors of biological bone mass determination as a function of muscle mass, force, and use is sex hormones, as discussed previously [14, 18, 44]. Moreover, the effects of sex hormones on bones may vary in different instances. In fertile women, estrogen effects on bone mass may be positive through an inhibition of negative-balance bone remodeling, or negative because of an inhibition of periosteal bone growth. Oppositely, in men, androgens exert little or no effects on bone remodeling but stimulate periosteal bone growth. The analysis of the mechanisms involved in these kinds of effects requires specifically designed studies, which is outside the scope of this discussion [9]. Other factors, including sex hormones, dietary patterns, drug use, and certain micronutrient intake, as well as age of menarche and contraceptive use in women, can influence bone determinations [8].

### Limitations of the study

The cross-sectional nature of the study precludes ascribing the observed results as direct “effects” of the different LTPAs. Nevertheless, the general coherence of the observations with other studies and interpretations allows us to suppose that what we describe here as “inter-group differences” could really reflect some (mechanical) influences of the selected discipline on the muscle-bone units of the studied individuals.

The study was not specifically designed to analyze the reported effects. Therefore, results could have been somewhat affected by differences in the number of individuals per group, the relative inequivalence of volume, intensity, and duration of the different activities, the lack of special dietary patterns for men and women, differences in ages in groups, and other similar factors which lie beyond the scope of the presented discussion.

The number of participants in our analysis may have worked against us, but despite this, we were able to test our hypothesis.

## Conclusions

Confirming our hypotheses, and despite the strong limitations posed by the study design, results may suggest that even at low volume values, the practice of relatively high-impact LTPAs (running, tennis, weights, basketball, soccer) could enhance both bone and muscle masses more efficiently than lower-impact activities (walking, cycling, swimming) or inactivity, as observed here. Interestingly, our study would also indicate that some higher-impact sports such as basketball and soccer could also improve the BMC-vs-LM relationship compared to medium- and low-impact activities. This would hierarchize activities that generate the greatest bone impact by how effectively they use the bone-muscle unit to reinforce bone structure within comparable levels of muscle mass, especially for long-bearing bones in men. Also, the apparently high level of region specificity of the observed differences suggests both the possibility and convenience of directionally orienting some specific exercises as a means to improve bone mass, preferably in specific skeletal sites.

The detection of such effects despite low levels of exercise volume supports the prescription of easy-to-follow exercise plans, specifically designed for adult men and fertile women. Such recommendations can serve as a public resource to improve the probability of achieving higher levels of bone mass, acting as one of the most effective means at hand to prevent the development of osteoporosis and bone frailty at an older age.

**Author contribution** The authors' responsibilities were as follows: ED-G and JS designed the study and secured funding; ED-G, RV-C, BR-P, PR-P, and JS conducted the research; PM-A, PC, ED-G, JLF, and GRC performed the statistical analyses; EDG, JLF, and GRC wrote the manuscript; EDG, RV-C, BR-P, PR-P, PM-A, PC, JLF, JS, and GRC critically reviewed the manuscript. All authors reviewed and commented on the manuscript. All authors read and approved the final manuscript.

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**Data availability** The data that support the findings of this study are available from the authors upon reasonable request.

## Declarations

**Ethics approval** The present study was conducted according to the Declaration of Helsinki guidelines. The ethics and research committees of all participating institutions [Comité de Ética e Investigación, Instituto Mexicano del Seguro Social (No.12CEI0900614); Comité de Ética e Investigación, Instituto Nacional de Salud Pública (No.13CEI1700736); Comité de Ética, Centro de Investigación en Ciencias Médicas (No.1233008X0236)] reviewed and approved the study protocol and informed consent forms.

**Consent to participate** Signed written informed consent was previously obtained from all participants.

**Consent for publication** All authors had final responsibility for the decision to submit for publication.

**Conflicts of interest** None.

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