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Frequency and duration of vigorous physical activity bouts are associated with adolescent boys' bone mineral status: a cross-sectional study

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Abstract

Purpose: Vigorous physical activity (VPA) has been proven to promote osteogenesis in adolescents; however the specifics of the optimal pattern of frequency and duration of VPA are unknown. The main goal of the present study was to analyze the associations of different length of VPA bouts with bone health.

Methods: 180 healthy male adolescents (11-13 years) had their bone mineral content and density assessed by dual-energy X-ray absorptiometry scans at the whole body, femoral neck (FN) and lumbar spine and their physical activity measured by an accelerometer during one week.

Results: VPA was the intensity with the strongest associations with bone mineral parameters especially at the FN. Subjects whose longest VPA bout was 5 minutes or above had higher FN bone mineral density (BMD) than those who did not complete any 5-minute bout and these differences were greater with participants who reached 15 consecutive minutes of VPA (>15': 0.977 ± 0.020g/cm2; 5'-15': 0.907 ± 0.009g/cm2; <5': 0.876 ± 0.009g/cm2; all p<0.05). When comparing the relevance of VPA bouts and volume of physical activity, the group with low volume and having a VPA bout had better FN BMD compared to the group with high volume but no VPA bout. Additionally, the group with both high volume and VPA bout showed better FN BMD than the rest of the groups.

Conclusions: VPA may be the most effective activity intensity to improve bone mineral density and content of adolescent boys, with greater benefits if VPA periods either long or frequent.

Keywords: Puberty; Osteoporosis; Osteopenia; Prevention; DXA, Physical activity bouts

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1. Introduction

Osteoporosis, a disease characterized by a low bone mineral density (BMD), shows a prevalence for people above 50 years of age of 6.6% for men and 22.1% for women in the European Union [1] and 16% and 29.9% for men and women respectively in the United States [2]. This bone fragility results in a reduced tolerance to stress and an increased fracture risk [3]. Osteoporotic fractures can, in turn, lead to reduced functionality, disability and even death [4]. Osteoporosis is already an economical burden for healthcare systems which is expected to rise in the coming years due to demographic changes [1]. Therefore, osteoporosis management and prevention is a main concern for developed countries [5,6].

One of the key strategies for preventing osteoporosis relies on maximizing the peak BMD [7,8] reached in early adulthood, since an increase of only 10% on this parameter has been shown to delay osteoporosis up to 13 years [9]. Adolescence is a critical stage for bone development, as 40% of adult bone mass is accumulated during the pubertal years [10]. It is estimated that around 60% of the interindividual variability in bone mass is due to endogenous factors such as race, sex or genetics [7]. Within the controllable factors that affect bone mass accrual, weight-bearing physical activity (PA) is among the ones with the highest impact and therefore an adequate management of this behaviour is crucial for a healthy bone development [11].

There are several reviews that show strong and consistent positive effects on bone development of sports practice [12,13], exercise interventions [14,15] and even participation in unstructured weight-bearing PA [16,17] during childhood and adolescence. Moreover, structural benefits obtained during puberty are retained later in life [18–20]. High-impact PA has been proven to be effective for improving BMD even in subjects with a worse genetic predisposition for bone development [21].

Vigorous weight-bearing physical activity (VPA) seems to be the most effective intensity for bone growth [22,23], even though some associations have been found among bone mineral parameters and total, light or moderate PA as well, whereas the negative influence of sedentary time has been observed [24,25]. Apparently, complying with the general recommendations of PA during childhood and adolescence may not be enough to guarantee an adequate bone development [26] and hence, specific recommendations of daily VPA have been proposed [24,27]. However, frequency, duration and distribution of VPA may alter the effectiveness of the specific adaptations [28]. Nonetheless, to our best knowledge, this has only been studied in animals [29] and in bone strength parameters at the tibia [28]. A better understanding of the optimal pattern of VPA for the improvement of adolescent bone health may be decisive for the development of PA recommendations and exercise interventions aimed for the prevention of osteoporosis.

Therefore, the main goal of the present investigation was to analyze the repercussion of objectively measured physical activity patterns on bone mass in healthy adolescents, focusing on the analysis of vigorous physical activity bouts and the overall volume of physical activity.

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2. Methods

2.1. Participants and study design

A total of 264 healthy Caucasian boys between 11 and 13 years of age from different schools in Tartu and its surroundings participated in this cross-sectional study between October 2010 and March 2011 [30–32]. The tests included anthropometry and bone mineral measurements, sexual maturation evaluation and physical activity registration. Participants and parents completed a questionnaire of about the child´s general health and development. Boys who had their participation in physical education classes restricted by a clinician (due to either chronic illness or medication contraindications) were excluded from the study, as well as those participants taking medications known to affect bone. No participant reported smoking or participating in weightlifting training.

The Human Ethical Committee of the University of Tartu, Estonia, approved the study protocol (179/T-4), which complied with the Declaration of Helsinki (revised in Fortaleza 2013). All the participants and their parents were given a full written description of the study characteristics and provided signed informed consent prior to the beginning of the tests. The subjects of the present study were part of a longitudinal study cohort where boys were followed until they reached pubertal maturity.

2.2. Anthropometry, maturation and bone mineral measurements

Height was measured to the nearest 0.1 cm using Martin's metal anthropometer and body mass to the nearest 0.05 kg with a medical scale (A&D Instruments Ltd; Abingdon; UK) while wearing underwear and no shoes. All anthropometric measurements were performed by the same technician and following the International Society for the Advancement of Kinanthropometry protocol. Body mass index was calculated dividing the body mass by the height squared (kg/m^2). In order to assess maturation status, skeletal age was determined with an X-ray scan at the left hand and wrist, according to the procedure of Greulich and Pyle [33,34].

Bone mineral content (BMC, g) and density (BMD, g/cm^2) were measured at the whole body (WB), lumbar spine (L2 to L4, LS) and femoral neck (FN) using dual-energy X-ray absorptiometry (DPX-IQ densitometer, Lunar Corporation, Madison, WI, USA). The measurements were performed in the medium scan mode, with standard positioning and participants wearing light clothing. The same examiner evaluated all the scans and results using the extended analysis option from the proprietary software, version 3.6. Coefficients of variation were established by duplicate measurement following repositioning of 20 boys and were below 2% for bone mineral measurements.

2.3. Physical activity assessment

In order to evaluate physical activity (PA) participation, participants wore a uniaxial accelerometer (GT1M Actigraph, Monrovia, CA, USA) during one week on their right hip. Data were aggregated into 15-second epoch periods and all intervals of 20 or more minutes with zero counts were excluded from the register [35,36]. Days in which the total duration of registered data was shorter than 10 hours were considered invalid. Finally, only registers with a minimum of three valid days (at least one of them during weekend) were included in the final analysis.

The intensity of the PA was established according to the Evenson cutpoints (sedentary ≤100 counts/min, light >100 counts/min, moderate ≥2296 counts/min and vigorous ≥4012 counts/min) [37,38]. According to the original study in which this specific cutpoints were described, one example of sedentary activity would be sitting in a chair, slow walking would be classified as light PA, stair climbing or brisk walking as moderate PA, and bicycling or running as VPA [37]. In order to analyze the distribution of VPA, the presence of VPA bouts was evaluated for each participant. To analyze the distribution of VPA over time, the consecutive periods (bouts) of VPA were analyzed. In order to be included in the analysis, the minimum duration of a bout was set at five consecutive minutes of VPA, with a tolerance of one epoch.

If participation in light and moderate PA was taken into consideration along with the VPA bouts, four groups can be defined. Participants were classified as either high or low volume according to the median value of light and moderate PA participation and as "VPA bout" or "no VPA bout" regarding whether or not they had at least one 5-minute bout of VPA during the measurement period (Supplementary table 1).

2.4. Statistical analysis

Statistical analyses were carried out with SPSS v22.0 for Windows (Chicago, IL, USA). After confirming the normality assumption with Kolmogorov-Smirnov tests, variables were explored for the presence of outliers. Descriptive statistics were obtained for anthropometric, physical activity and bone mineral variables and presented as mean ± standard deviation. Partial Pearson's correlation coefficients among bone mineral and physical activity variables were calculated after adjusting by body mass and skeletal age. Receiver-operator characteristics (ROC) curves analysis was performed to evaluate the adequacy of physical activity parameters for predicting bone mineral outcomes. Analysis of covariance was applied to assess differences in bone mineral status between different PA participation profiles, with Bonferroni post-hoc tests. Statistical significance was set at $p<0.05$.

3. Results

From the original sample of 264 subjects, a total of 180 participants completed all body composition measurements and provided valid accelerometry data to fulfill inclusion criteria. The anthropometric characteristics, physical activity participation and bone mineral parameters of the sample are presented in table 1. No differences in height, weight, BMI and both skeletal and chronological age were found between excluded and included boys (data not shown).

Table 2 shows the relationships among physical activity, BMC and BMD at different sites, after adjusting by body mass and skeletal age. The skeletal site that showed the highest correlation with PA participation was the femoral neck, where both BMC and BMD presented significant correlations with moderate and VPA as well as with the total PA (all $p<0.05$). Moreover, VPA was positively correlated with whole body and lumbar spine BMC and total PA was related to whole body BMC and BMD (all $p<0.05$).

Body mass and maturation-adjusted median bone mineral values were used to classify participants according to their current bone health status. After performing ROC curves analysis for all activity intensities in each skeletal site, only VPA yielded significant results for whole body, femoral neck and lumbar spine BMC and femoral neck BMD (area under the curve (AUC) of 0.605, 0.634, 0.616 and 0.608 respectively, figure 1). Daily time spent at different physical activity intensities was compared between

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those subjects who were above the median for all bone mineral parameters and those who were below the median in all of them. Particpants who had bone mineral parameters above the median at all regions (categorized as "good overall status") spent more time in VPA and had a higher overall physical activity participation compared to those labelled as "bad overall status", who were consistently below the median in all six bone variables ($p<0.05$; table 3).

Adolescents who engaged in VPA for five consecutive minutes at least once during the testing period had higher BMC and BMD at the femoral neck and the whole body compared to those who didn't ($p<0.05$; Table 4). However, if the frequency of the participation in these 5-minute VPA bouts was less than once for every three days, the differences disappeared. Additionally, further improvements were observed in those boys who extend their practice of VPA for at least 15 consecutive minutes (all $p<0.05$; table 4).

Four different groups were defined according to the volume and intensity of PA. The comparison among these groups is presented in table 5, which indicates that there were significant differences in femoral neck BMD among all four groups showing that the higher the volume and the intensity the higher the bone parameters (all $p<0.05$, figure 2). Additionally, both "VPA bout" groups showed higher values of whole body and femoral neck BMC compared to the "low volume - no VPA bout" group (all $p<0.05$; table 5).

4. Discussion

The main finding of the present study was the acknowledgement of the importance of accumulating VPA activity in continuous periods of at least 5 minutes for the improvement of whole body and femoral neck bone health in male adolescents.

As expected, among the different intensities of PA, VPA presented the strongest relation with bone mineral parameters; being the only intensity with statistically significant relationships with whole body and lumbar spine BMC values and the highest correlation coefficients with femoral neck BMC and BMD. These results are in agreement with the current evidence regarding the effect of PA on bone health, which points towards VPA or moderate-to-vigorous PA as the ideal intensities to elicit bone growth [22,39,40]. It should be noted that overall PA also indicated significant relationships with whole body and femoral neck BMC and BMD, suggesting that PA volume may also play a role in bone development. Similar results have been reported in other studies [41,42] and this relationship may be exclusive to boys [42].

The skeletal region that seemed to be more affected by all moderate, vigorous and overall PA was the femoral neck. This site is of special importance for osteoporosis prevention, since it is one of the most prevalent locations of osteoporotic fractures [1]. Moreover, the detection of osteoporosis is based on the measurement of femoral neck BMD [43]. These results may be due to the highest responsiveness of cortical bone in contrast to trabecular bone [44,45]. However, this cannot be inferred from our results, as the methods used for bone mineral assessment do not allow for the differentiation between cortical and trabecular bone.

Regarding the ROC curves analyses, even though VPA reached statistical significance for the classification of bone mass status, the correspondent AUC were low and therefore the accuracy of VPA to

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stratify the sample according to bone mineral parameters was limited. It has been proposed that VPA and moderate-to-vigorous PA are best fit to identify those individuals with excellent bone health (>2 SD above the mean) rather than those with poor bone mineral status (>1 SD below the mean) [26]. Unfortunately, we were not able to test these results within our sample, since only 5 participants presented BMC values corresponding to the excellent category. However, when grouping the sample according to the global bone mass status, higher levels of vigorous and total PA were found among those subjects who were consistently above the median value for BMC and BMD at every skeletal site than those participants that were consistently below the median. This finding further highlights the importance of VPA for bone mass of male adolescents.

It has been suggested that not only the time spent in VPA but also the pattern of this activity might be relevant for bone accretion during puberty [28]. In order to test that, accelerometry registers were scanned and all periods of at least five consecutive minutes of VPA were retrieved for each subject. Both the quantity and the maximum duration of these periods showed a positive association with whole body and femoral neck BMC and BMD within the sample. More specifically, it seems that it is necessary to participate in VPA bouts at least once every three days for 5 consecutive minutes in order to benefit from this improvement. Additionally, those participants who engaged in VPA for longer periods (15 consecutive minutes or more) had even higher bone mass and density at the femoral neck and at the whole body. These results suggest that in order to optimize the beneficial effects of PA on bone health when developing PA recommendations or designing exercise interventions, VPA practice should be aggregated in periods of at least 5 minutes, taking into account that if it is possible to extend the duration or frequency, better results should be expected.

To our knowledge, one study has analyzed the relative importance of light and moderate to VPA and found that those subjects with a higher proportion of moderate-to-vigorous PA presented higher values of subtotal BMC, BMD and bone area [46]. In order to analyze the importance of volume and intensity of physical activity the sample was split according to the presence of at least one 5-min VPA bout and then both groups were further subdivided using the median score of the daily minutes of light and moderate PA. The relative homogeneity of the sample sizes of the different groups should be highlighted, since it shows that PA volume and intensity may be considered as independent entities. According to our results, all four groups differed in their femoral neck BMD content with the "high volume – VPA bout" group presenting the highest values, followed by the "low volume – VPA bout" category. It is interesting to note that in comparison to the "low volume – no VPA bout" group, only those adolescents in the "VPA bout" groups showed higher values of whole body and femoral neck BMC, whereas the "high volume – no VPA bout" category did not present these improvements. According to these results, an increase in both volume and intensity of PA can be beneficial for the least active subjects, but the focus should be put in participating in VPA.

This study has some limitations that should be acknowledged. The cross-sectional design of the study did not allow to infer causal relationships. Also, the lack of a nutritional assessment made controlling the calcium intake impossible. Moreover, as it has been mentioned, even though a reference standard method was used for the bone mineral assessment it does not allow to differentiate between cortical and

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trabecular tissue and therefore bone structure was not analyzed. Additionally, the impossibility of analyzing the raw acceleration data directly hindered the precise evaluation of the number of impacts at different intensity levels and its effects on bone structure, as suggested by Vainionpää et al. [47]. It should also be taken into account that these results are only applicable for early pubertal boys. Research is needed to clarify if these effects are also present in girls, since they follow a different maturation process. Further research could also clarify the specific effects of VPA bouts on cortical and trabecular bone and longitudinal studies could analyze the evolution of BMC and BMD in relation to diverse VPA patterns.

4.1. Conclusions

Taking into account that both volume and intensity of PA are relevant, VPA seems to be the most effective activity intensity to improve bone mineral density and content of adolescent boys, especially at the femoral neck. These benefits appear when VPA is accumulated in uninterrupted periods of 5 minutes for at least once every three days and can be even greater if the duration is extended to 15 minutes of consecutive VPA.

4.2. Funding

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Table 1 – Descriptive characteristics of the sample (n=180) [a]

Anthropometry	
Chronological age (y)	12.07 ± 0.69
Skeletal age (y)	11.87 ± 1.06
Height (cm)	154.6 ± 7.7
Body mass (kg)	47.1 ± 12.5
BMI (kg/m^2)	19.5 ± 4.1
Physical activity	
Sedentary time (min/d)	544.3 ± 76.0
Light PA (min/d)	237.6 ± 47.5
Moderate PA (min/d)	40.3 ± 14.2
Vigorous PA (min/d)	19.5 ± 13.6
Total PA (counts/min)	486.3 ± 149.1
Bone mineral parameters	
WB BMC (g)	1702 ± 346
WB BMD (g/cm^2)	0.976 ± 0.066
FN BMC (g)	4.067 ± 0.642
FN BMD (g/cm^2)	0.899 ± 0.092
LS BMC (g)	26.87 ± 6.22
LS BMD (g/cm^2)	0.822 ± 0.091

BMI: Body mass index; PA: Physical activity
WB: Whole body; FN: Femoral neck; LS: Lumbar spine
BMC: Bone mineral content; BMD: Bone mineral density
[a] Values are expressed as mean ± standard deviation

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Table 2 – Partial correlation coefficients between physical activity intensities and bone mineral parameters, adjusted by body mass and skeletal age (n=180) [a]

	Sedentary (min/d)	Light PA (min/d)	Moderate PA (min/d)	Vigorous PA (min/d)	Total PA (counts/min)
WB BMC (g)	-0.045	-0.049	0.094	**0.234**	**0.193**
WB BMD (g/cm^2)	-0.089	-0.081	0.087	0.141	**0.168**
FN BMC (g)	-0.127	0.042	**0.254**	**0.364**	**0.337**
FN BMD (g/cm^2)	-0.108	0.039	**0.238**	**0.317**	**0.308**
LS BMC (g)	0.041	-0.047	0.065	**0.201**	0.138
LS BMD (g/cm^2)	0.042	-0.133	0.000	0.096	0.074

[a] Bold characters indicate significant correlations ($p<0.05$)
PA: Physical activity; WB: Whole body; FN: Femoral neck; LS: Lumbar spine
BMC: Bone mineral content; BMD: Bone mineral density

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Table 3 – Physical activity profile comparison between bone mineral status categories [a]

	Bad overall status (n= 66)	Good overall status (n= 63)
Sedentary time (min/d)	551.6 ± 69.6	540.1 ± 75.2
Light PA (min/d)	234.2 ± 43.2	241.5 ± 56.0
Moderate PA (min/d)	38.5 ± 13.4	41.2 ± 14.1
Vigorous PA (min/d)	17.0 ± 12.2	22.5 ± 14.3*
Total PA (counts/min)	456.0 ± 127.8	516.9 ± 168.6*

*Significant differences between the groups (p<0.05)
PA: Physical activity
[a] Values are expressed as mean ± standard deviation

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Table 4 – Bone mineral parameters after adjustment by weight and biological age in relation with VPA bouts occurrence, frequency and duration [a]

Existence of any 5-min VPA bout	No (n=83)	Yes (n=97)
WB BMC (g)	1662 ± 18	1737 ± 17*
WB BMD (g/cm^2)	0.967 ± 0.005	0.984 ± 0.005*
FN BMC (g)	3.92 ± 0.05	4.19 ± 0.05*
FN BMD (g/cm^2)	0.876 ± 0.009	0.918 ± 0.008*
LS BMC (g)	26.46 ± 0.49	27.24 ± 0.45
LS BMD (g/cm^2)	0.816 ± 0.008	0.828 ± 0.008

Frequency of 5-min VPA bouts	No bout (n=83)	Less than once every 3 days (n=41)	At least once every 3 days (n=56)
WB BMC (g)	1662 ± 18	1723 ± 25	1748 ± 22*
WB BMD (g/cm^2)	0.967 ± 0.005	0.979 ± 0.007	0.988 ± 0.006*
FN BMC (g)	3.92 ± 0.05	4.07 ± 0.07	4.28 ± 0.06*
FN BMD (g/cm^2)	0.876 ± 0.009	0.903 ± 0.012	0.93 ± 0.011*
LS BMC (g)	26.46 ± 0.49	26.8 ± 0.69	27.56 ± 0.59
LS BMD (g/cm^2)	0.816 ± 0.008	0.826 ± 0.012	0.83 ± 0.01

Maximum VPA bout duration	No bout (n=83)	Less than 15 min (n=81)	At least 15 min (n=16)
WB BMC (g)	1662 ± 18	1730 ± 18*	1773 ± 41*
WB BMD (g/cm^2)	0.967 ± 0.005	0.981 ± 0.005	1.000 ± 0.011*
FN BMC (g)	3.92 ± 0.05	4.14 ± 0.05*	4.46 ± 0.12*†
FN BMD (g/cm^2)	0.876 ± 0.009	0.907 ± 0.009*	0.977 ± 0.020*†
LS BMC (g)	26.46 ± 0.49	27.04 ± 0.49	28.24 ± 1.10
LS BMD (g/cm^2)	0.816 ± 0.008	0.827 ± 0.008	0.832 ± 0.019

* Significant differences compared to the group with no bouts ($p<0.05$)
† Significant differences compared to the group “less than 15 min” ($p<0.05$)
VPA: Vigorous physical activity WB: Whole body; FN: Femoral neck; LS: Lumbar spine
BMC: Bone mineral content; BMD: Bone mineral density
[a] Values are expressed as mean ± standard error

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Table 5 – Body mass and biological age-adjusted bone mineral parameters across different PA patterns [a]

	Low volume No VPA bout (n=41)	High volume No VPA bout (n=42)	Low volume VPA bout (n=49)	High volume VPA bout (n=48)
WB BMC (g)	1640 ± 25	1683 ± 25	1737 ± 23*	1738 ± 24*
WB BMD (g/cm^2)	0.969 ± 0.007	0.965 ± 0.007	0.981 ± 0.006	0.987 ± 0.007
FN BMC (g)	3.81 ± 0.07	4.03 ± 0.07	4.11 ± 0.07*	4.28 ± 0.07*
FN BMD (g/cm^2)	0.855 ± 0.012	0.897 ± 0.012*	0.91 ± 0.011*†	0.926 ± 0.011*†‡
LS BMC (g)	25.9 ± 0.7	27 ± 0.7	27.3 ± 0.6	27.1 ± 0.6
LS BMD (g/cm^2)	0.817 ± 0.012	0.815 ± 0.012	0.833 ± 0.011	0.823 ± 0.011

* Significant differences compared to the "low volume – no VPA bout" group ($p<0.05$)
† Significant differences compared to the "high volume – no VPA bout" group ($p<0.05$)
‡ Significant differences compared to the "low volume – VPA bout" group ($p<0.05$)
PA: Physical activity; WB: Whole body; FN: Femoral neck; LS: Lumbar spine
BMC: Bone mineral content; BMD: Bone mineral density
[a] Values are expressed as mean ± standard error

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Highlights

- Vigorous physical activity is related with bone health in early pubertal boys.
- Frequency and duration of vigorous physical activity are linked with bone status.
- Benefits are higher if vigorous physical activity lasts longer than 15 minutes.
- Both volume and intensity of physical activity are important for bone health.

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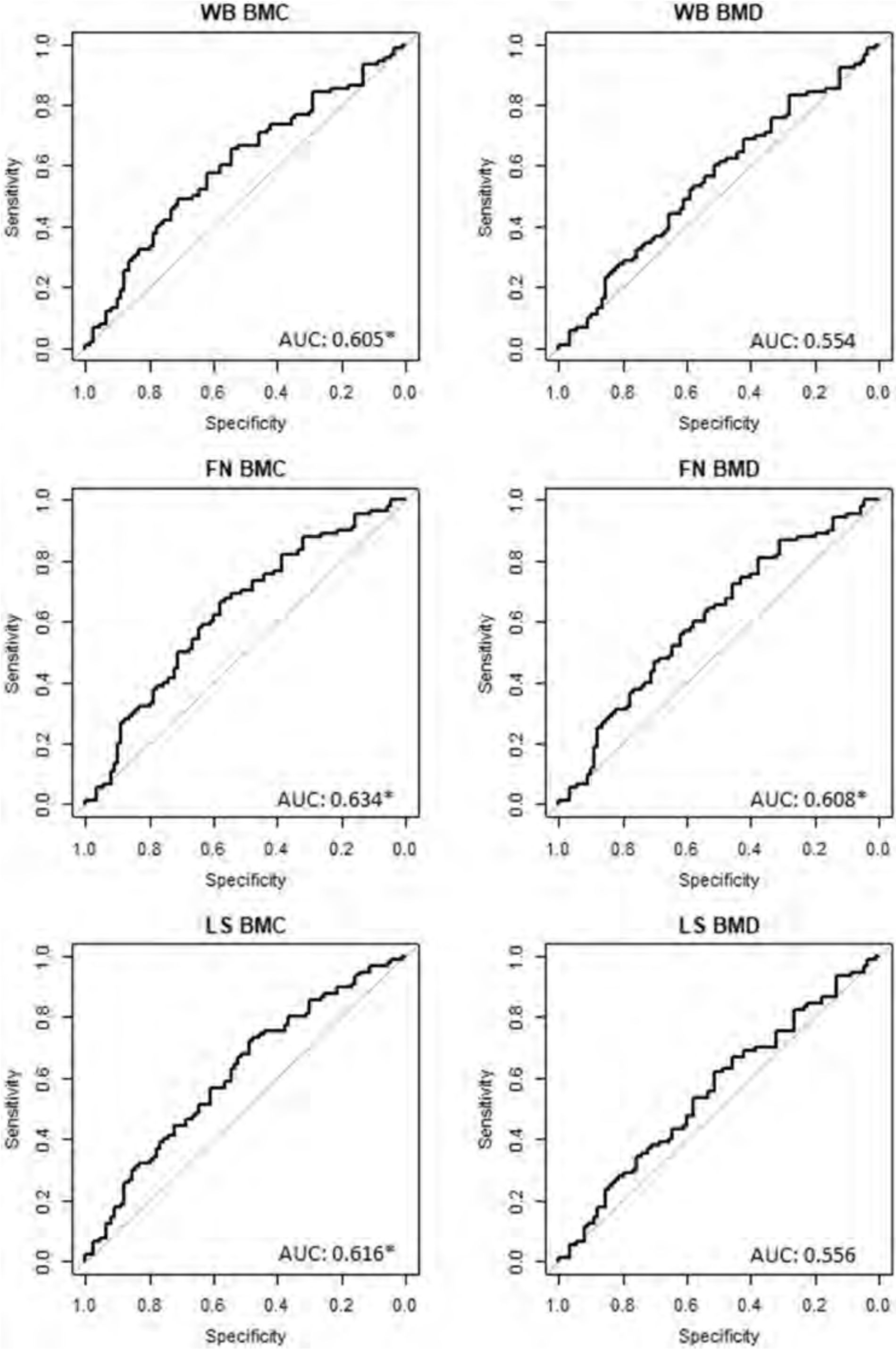
WB BMC
AUC: 0.605*
WB BMD
AUC: 0.554
FN BMC
AUC: 0.634*
FN BMD
AUC: 0.608*
LS BMC
AUC: 0.616*
LS BMD
AUC: 0.556
Sensitivity
Specificity
1.0
0.8
0.6
0.4
0.2
0.0

Figure 1

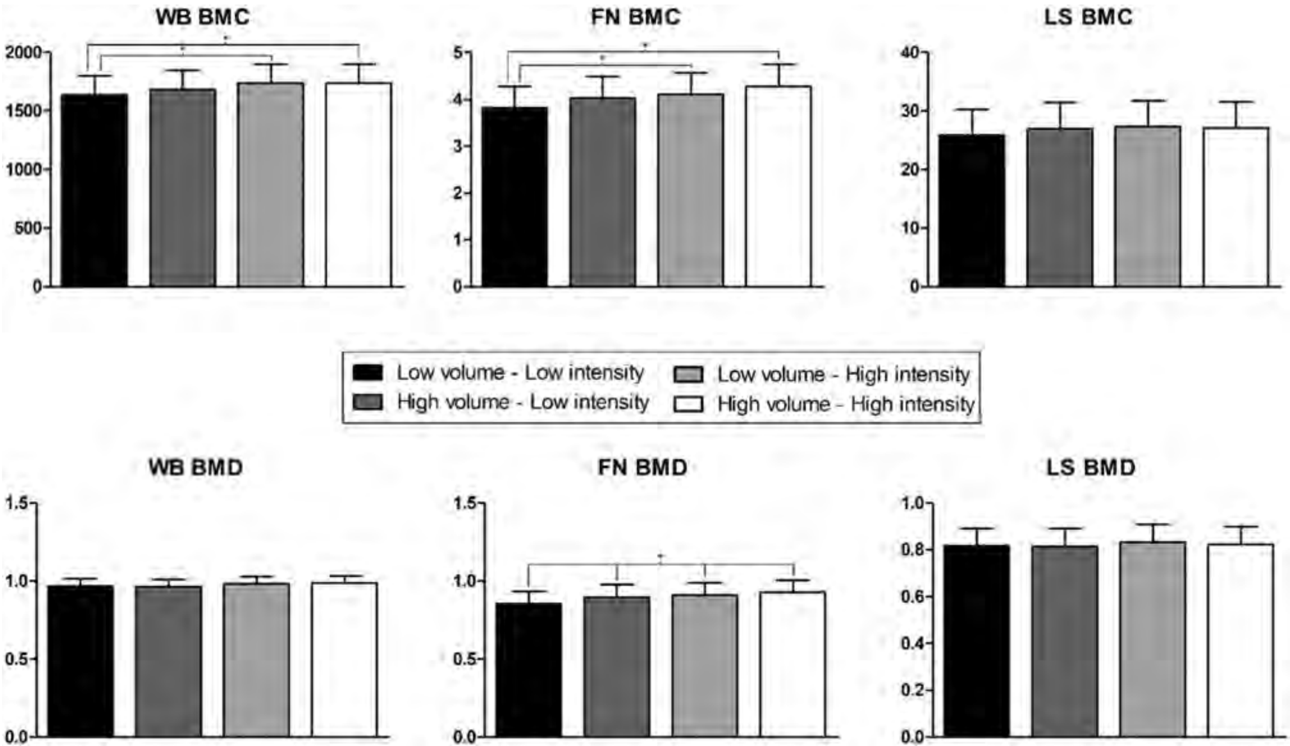
WB BMC
2000
1500
1000
500
0
FN BMC
5
4
3
2
1
0
LS BMC
40
30
20
10
0
Low volume - Low intensity
High volume - Low intensity
Low volume - High intensity
High volume - High intensity
WB BMD
1.5
1.0
0.5
0.0
FN BMD
1.5
1.0
0.5
0.0
LS BMD
1.0
0.8
0.6
0.4
0.2
0.0

Figure 2